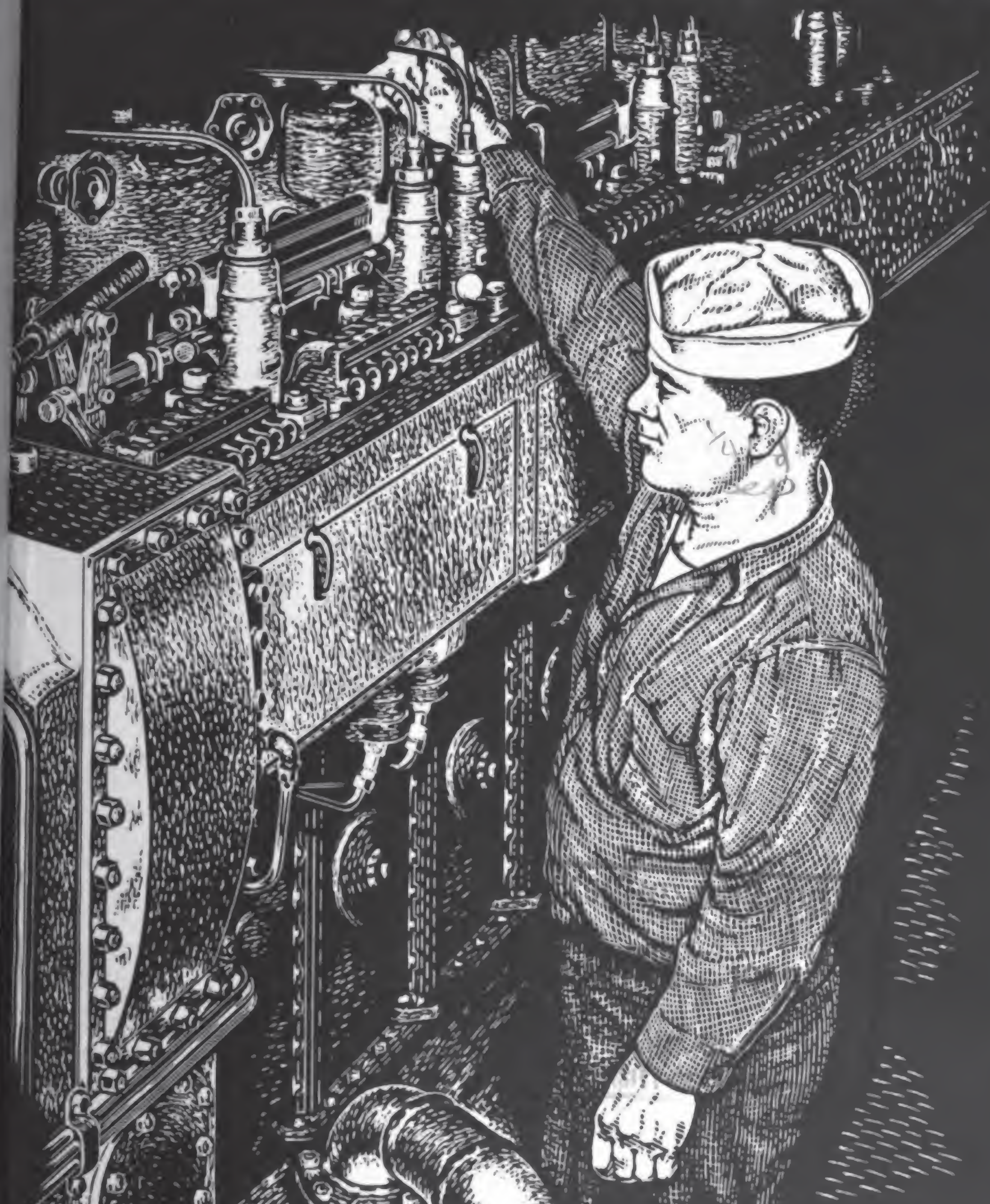

NAVPERS 10540

ENGINEMAN 2

NAVY TRAINING COURSES

ENGINEMAN 2

Prepared by

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10540

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CREDITS

All illustrations published in *Engineman 2* are official U. S. Navy illustrations, unless designated below.

Source	*Figures*
American Bosch Corporation, Springfield, Mass.	6–5, 6–6, 6–7, 6–8, 6–9, 6–10, 6–19, 6–20, 6–21, 6-28, 6–29.
American Society of Mechanical Engineers, New York, N. Y.	3–13, 3–14.
E. B. Badger & Sons Co., Boston 14, Mass.	12–3, 12–5, 12–6.
Ex-Cell-O Corporation, Detroit, Michigan	6–11, 6–13, 6–14.
Fairbanks, Morse & Co., Chicago, Illinois	6–27, 8–8(B), 8–14, 8–16(A).
General Motors Corporation,	
Cleveland Diesel Engine Division	8–26, 8–31, 8–35.
Detroit Diesel Engine Division	6–22, 6–23, 8–18(B), 8–23, 8–28.
Theo. Audel and Company, New York, N. Y.	5-5.
U. S. Naval Institute, Annapolis, Maryland	5–11, 5–16, 5–18, 11–1, 11–3, 11–4.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
SERVICE	4 mos. service—or completion of recruit training.	6 mos. as E–2 or 8 mos. total service.	6 mos. as E–3 or 14 mos. total service.	12 mos. as E–4.	12 mos. as E–5; total service at least 36 mos.	36 mos. as E–6.
SCHOOL	Recruit Training.		Class A for PR3, PRS3.		Class B for MN1.	Class B for AGCA, MNCA, MUCA.
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.			
PRACTICAL FACTORS	Locally prepared check-offs.		Records of Practical Factors, NavPers 760, must be completed for all PO advancements.			
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.			
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.			
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E–3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.				
AUTHORIZATION	Commanding Officer		U. S. Naval Examining Center			BuPers
	TARS are advanced to fill vacancies and must be approved by district commandants or CNARESTRA.					

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48 12 NON-DRILLING	9 mos. 9 mos. 12 mos.	9 mos. 15 mos. 24 mos.	15 mos. 21 mos. 24 mos.	18 mos. 24 mos. 36 mos.	24 mos. 36 mos. 48 mos.	36 mos. 42 mos. 48 mos.
DRILLS ATTENDED IN GRADE#	48 24 12	27 16 8	27 16 13	45 27 18	54 32 20	72 42 32	108 64 38
TOTAL TRAINING DUTY IN GRADE#	24 OR 48 12 NON-DRILLING	14 days 14 days None	14 days 14 days None	14 days 14 days 14 days	14 days 28 days 14 days	28 days 42 days 28 days	42 days 42 days 28 days
PERFORMANCE TESTS				Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316, must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation of petty officers, officers and approval by commanding officer required for all advancements.

#Active duty periods may be substituted for drills and training duty.

READING LIST

NAVY TRAINING COURSES

Engineman 3, NavPers 10539
Basic Hand Tool Skills, NavPers 10085
(metal working skills only)
Blueprint Reading and Sketching, NavPers 10077–A
(Chapters 1–6, 10)

OTHER NAVY PUBLICATIONS

Fundamentals of Diesel Engines, NavPers 16178–A
(Chapters 1, 2)
BuShips *Manual*, Chapters 45; 58

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for supplementary reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:*

CORRESPONDENCE

Number	Title
CC 290	*Physics I*
CB 781	*Fundamentals of Electricity*
CB 794	*Principles of Diesel Engines*

SELF-TEACHING

MC 290	*Physics I*
MB 781	*Fundamentals of Electricity*
MB 794	*Principles of Diesel Engines*

*"Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders."

CONTENTS

PREFACE

This training course has been written for enlisted men of the regular Navy and of the Naval Reserve who are preparing for advancement to Engineman 2. Study of this training course should be combined with practical experience; with review of other applicable Navy Training Courses; and with study of manufacturers' instruction books, BuShips *Manual*, and other pertinent material.

Qualifications for advancement to Engineman 2 are listed in appendix II at the back of this publication. Since the examinations for advancement are based upon these qualifications, it is suggested that the reader refer to them frequently for guidance.

This training course provides the Engineman 2 with information which will assist him in meeting the required practical and examination factors applicable to the rate. The first chapter of this training course discusses the duties and responsibilities of the Engineman 2; in addition, chapter 1 contains information concerning the general scope of the Engineman rating. The remainder of this training course contains information dealing primarily with the systems and equipment which will be operated and maintained by the Engineman 2.

As one of the Navy Training Courses, *Engineman 2* has been prepared by the U. S. Navy Training Publications Center for the Bureau of Naval Personnel. Technical assistance has been furnished by the Bureau of Ships and by the U. S. Naval Schools, Enginemen, U. S. Naval Training Center, Great Lakes.

ENGINEMAN 2

CHAPTER 1

ADVANCEMENT TO EN 2

Current qualifications for advancement to EN 2 require that the applicant be able to start, operate, and secure Diesel generators; he must be able to renew cylinder liners, pistons, rings; spot in and replace centrifugal pump bearings; test evaporators and condensers for salt water leaks; test refrigeration and air-conditioning plants for refrigerant leaks, and test for viscosity of fuel and lubricating oils.

QUALIFICATIONS FOR ADVANCEMENT IN RATING

In order to fully understand the requirements for advancement to EN 2, you must make a careful study of the Engineman qualifications listed in the *Manual of Qualifications for Advancement in Rating*, NavPers 18068, Revised ("Quals Manual"). The portion of this *Manual* which deals with Engineman qualifications is given in appendix II of this training course.

You have used these "Quals" as a guide in preparing for advancement to the rate of EN 3; use them now as a guide in studying for EN 2. As you study the qualifications for advancement in rating, remember that the qualifications listed represent the MINIMUM requirements for each rate. Compare the required qualifications with those you now possess. If you doubt your ability to meet any of the required factors, study appropriate Navy training courses,

manufacturers' instruction books, applicable chapters of BuShips *Manual,* and any other available reference material which will be of value to you.

In addition to reviewing and studying the printed material, you should check yourself out on equipment to make certain that you can meet the practical, as well as the examination, factor requirements. Extensive review of both written material and practical factors will be necessary before you can meet the requirements for the next higher rate.

ADDITIONAL RESPONSIBILITIES

Before you can advance in rating you must meet certain military and professional requirements. As an EN 3, you have mastered basic skills, you have become familiar with the terminology applicable to internal combustion engines as well as other equipment, and you have learned to answer many technical questions asked by lower rated men. Along with this increase in knowledge, you have gradually assumed greater responsibilities. However, the rate for which you are now preparing requires an additional degree of knowledge and skill, a willingness to assume greater responsibilities, and an ability to lead men.

Every petty officer must be a technical specialist in his own field. As you advance in rating, however, it will become increasingly important for you to understand the duties and responsibilities of men in related ratings, and to understand how the entire Engineering Department functions. You must learn to know what work is done, and what equipment is used by personnel of other Engineering and Hull group ratings. (The eleven other ratings of the Engineering and Hull group are: Machinist's Mate, Machinery Repairman, Boilerman, Boilermaker, Electrician's Mate, I. C. Electrician, Metalsmith, Pipe Fitter, Damage Controlman, Patternmaker, and Molder.) Although it is true that many maintenance and repair jobs can be properly handled within your own

division, some jobs will require skills and equipment found only in another division. Therefore, you must learn to work with the rest of the Engineering Department, and to utilize the skills and technical knowledge of men, when necessary, in the ratings mentioned above.

Military Duties

Military requirements for advancement are those general requirements, such as watch standing, first aid, and military conduct, which apply to all enlisted personnel. As you advance in the Engineman rating, your military duties will become increasingly important. You will have an increasing responsibility for showing other men what to do and how to do it, and for inspecting their work.

A detailed consideration of the military requirements for your rating is beyond the scope of this training course. The military requirements for enlisted personnel are published as part of the Quals Manual. They are also discussed in the *General Training Course for Petty Officers,* NavPers 10055.

Professional Duties

The professional, or technical, qualifications are those which enlisted personnel must have to properly perform the duties of a rate within a specific rating. As you advance in your rating, it will become increasingly important for you to understand every requirement of the Engineman rating; an ENC must have a thorough knowledge of every requirement for his rating.

The professional requirements for all Navy enlisted ratings are published in the Quals Manual. The section of the professional requirements that applies to the Engineman rating has been reproduced in appendix II of this training course. That section has been used as a guide in the preparation of this training course. In addition, it will be used as a guide by those who prepare the service-wide competitive examinations for your rating. Therefore, it is important for you to refer to the back of

this training course and become familiar with the qualifications for advancement in the Engineman rating.

GENERAL AND EMERGENCY SERVICE RATINGS

The Engineman rating has a dual breakdown in classification — the general service and emergency service ratings.

The GENERAL SERVICE RATING, for Engineman, is classified as EN. This rating applies during normal peacetime operations, and covers the entire field of the Engineman responsibilities. The training mission of the peacetime Navy is to produce broadly qualified, versatile personnel who, in time of emergency, can be advanced to positions of greater responsibility and authority.

The rating structure must be flexible in order to permit expansion, during a national emergency, from broad, general service areas to narrower emergency service areas within the same rating. To provide for this expansion, EMERGENCY SERVICE RATINGS were established.

During a national emergency, the Engineman rating is divided into two specialized groups called emergency service ratings: Diesel Enginemen (END) and Gasoline Enginemen (ENG). The duties in each group are based primarily on the type of engine and the related equipment with which the Engineman must be familiar.

Following a national emergency and upon returning to a peacetime organization, regular Navy personnel in emergency service ratings will be required to qualify for a general service rating. Members of the Naval Reserve, however, will be carried in their proper emergency service ratings. If a Reserve Engineman wishes to ship over to the regular Navy in peacetime, he must meet all the requirements of the general service Engineman rating.

THE ENGINEMAN RATING

The duties and responsibilities which you have learned to assume as an EN 3, as well as a Fireman, represent a small portion of those which you must be able to assume

as you advance in the Engineman rating. Depending upon the duty station and the type of engine installation, the duties of the Engineman will vary. From your past experience, you know that the responsibilities of the Engineman include the operation, maintenance, and repair of internal combustion engines. The Engineman must also know how to operate and maintain auxiliary engineroom, refrigeration, and air-conditioning equipment. In order to perform their duties efficiently, Enginemen must have a thorough understanding of the equipment they are responsible for operating and maintaining properly. In addition, they must possess a general knowledge of the over-all operation of the division and of the ship to which they are assigned. In brief, these are the over-all requirements of the Engineman rating. In order to advance in rate, the Engineman must be able to satisfactorily meet all the practical requirements of the rate and have a thorough knowledge of all the examination subjects listed in appendix II of this training course.

Duties of the EN 2

Careful study of the quals for EN 2 requires you to learn to do a number of tasks. For example, you will be required to know how to make operational adjustments to clutches on small boat engines. You will make certain repairs such as repacking high-pressure valves, and refacing valve seats and disks. You will be responsible for the operation of gasoline engine units, reciprocating gear, and centrifugal pumps, as well as other auxiliary machinery. You will be required to know the procedures involved in making viscosity tests on fuel and lubricating oil. Above all, you will be required to know how to renew cylinder liners, pistons, and rings in internal combustion engines.

Preparing for Advancement to EN 2

As you prepare for advancement in rating, it is best to learn all you can by actually working with the ship's

machinery and equipment. Instruction books, manuals, and illustrations cannot take the place of the "know how" that you acquire by practical experience. If you are required to possess a working knowledge of any machines or equipment not installed on your ship, arrange to observe and study these machines on another ship, if possible.

Practical experience, however, does not provide all that is necessary for advancement. Although much "know how" is required in the engineroom, a great deal of "know why" is also necessary. In general, an understanding of the principles of operation of a machine, or unit, can best be obtained by reading and studying. Your ability to operate, maintain, and repair a machine will be increased if you know why a machine operates the way it does. In addition, you will be able to determine the causes of faulty operation. A man who only knows HOW to do something is not likely to be as useful as one who knows how to do it and WHY it should be done. Therefore, in addition to learning all you can from practical experience, you must become familiar with the available sources of information which are applicable to your rating.

SOURCES OF INFORMATION

Since this training course does not include detailed information on military requirements, and since the information it offers on professional requirements cannot be all-inclusive, you will need additional sources of information. A working list of material to be studied by enlisted personnel seeking advancement in rating is given in the *Training Courses and Publications for General Service Ratings,* NavPers 10052–E. Since this publication is revised frequently, be sure that you consult the most recent edition.

References on Military Requirements

The basic reference on military requirements for Po2's is the *Military Requirements for Petty Officers 3 and 2,*

NavPers 10056. A knowledge of the material contained in this book is mandatory for all petty officers 3 and 2. Additional information on all military requirements can be obtained from other publications listed in the current *Training Courses and Publications for General Service Ratings,* NavPers 10052.

References on Professional Requirements

A great deal of information which will help you meet the professional (technical) requirements for advancement is contained in the instruction books prepared by the manufacturers of the various units of machinery. In addition, BuShips *Manual* contains valuable information concerning the operation and maintenance of most of the machinery with which you will be working.

The current edition of *Training Courses and Publications for General Service Ratings* should be consulted for other references concerning the professional qualifications for advancement. Some sources of information which may be helpful to you are:

Basic Electricity, NavPers 10086
Basic Hand Tool Skills, NavPers 10085
Basic Hydraulics, NavPers 16193
Blueprint Reading and Sketching, NavPers 10077–A
Bureau of Ships Manual
  Chapter 41—Main Propelling Machinery (Section II, Diesel Engines; and Section V, Gasoline Engines)
  Chapter 45—Lubricants and Lubrication Systems
  Chapter 58—Distilling Plants
  Chapter 59—Refrigeration
Engineman 3, NavPers 10539
Fireman, NavPers 10520–A
Fundamentals of Diesel Engines, NavPers 16178–A
Mechanic 3 & 2, NavPers 10644–B

Most of the publications listed above are revised at frequent intervals, in order to bring the material up-to-date. When referring to any publication, see that you are using the most recent, revised edition available. The current *List of Training Publications,* NavPers 10061,

contains the titles, NavPers numbers, and latest edition dates of available Navy training courses.

SCOPE OF THIS TRAINING COURSE

The purpose of this training course is to help you meet the professional (technical) qualifications for advancement to EN 2. This training course contains information dealing primarily with the systems and equipment with which you will be working. This information will aid you in meeting the required practical, as well as the examination factors applicable to the EN 2 rate. Chapters 2, 3, and 4 of this course deal with starting systems, mechanical and fluid drives, and Diesel-electric drives. Chapters 5, 6, and 7 cover pumps, fuel injection equipment, and carburetors. In chapters 8 and 9, engine maintenance and testing of fuel and lube oils are covered. Gas turbine engines are covered in chapter 10. The next two chapters (11 and 12) deal with auxiliary machinery and equipment, and distilling plants. Chapters 13 and 14 contain information, applicable to the EN 2 rate, on refrigeration and air-conditioning equipment.

At the end of each chapter of this training course there is a quiz section. By referring to the quiz section, you will be able to check on what you have learned from study of the material in the chapter. The answers to each quiz are in Appendix I. Try to answer the questions before looking at the answer in the appendix. If you cannot answer any question correctly, read the subject matter again. Then, if you are still doubtful about the subject, ask a leading petty officer of your division to explain the material to you.

TRAINING TO BECOME A LEADER

As you advance in the Engineman rating, your military duties become more important. In addition to becoming a specialist in an occupational group, you will have an increasing responsibility for showing other men what to do and how to do the task, and for checking their work. You

will be expected to provide the supervision and instruction which those men need in order to advance in their rating. Therefore, as a petty officer you are training to become a leader as well as a technical specialist.

Effective Supervision

There are many skilled workmen, thoroughly familiar with every phase of their specialty, who must learn to supervise the work of others. Supervision is a job in itself and if you want to advance in your rating, you must learn how to do it.

When you're in charge of a detail, you'll supervise lower rated men and strikers. It will be necessary for you to assign work to these men and to see that it is properly completed. Of course, it is not necessary, or desirable, to be "breathing down a man's collar" while he is trying to perform a task, but you must be ON HAND to see that things go right and to give advice when it is needed.

Good supervision may be achieved by observing the following steps:

1. PLAN the job thoroughly, so that you know exactly WHAT is to be done, and, as far as possible, HOW you are going to meet the problems which are likely to arise.

2. EXPLAIN the assignment clearly enough so that the individual who is going to do the job understands just what is to be done.

3. CHECK the progress of the job, particularly in the early stages, to catch mistakes before they can result in excessive loss of time, labor, and material.

4. SUGGEST methods for doing the job, but allow the man to select any method which will result in a job well done.

5. ENCOURAGE quality in all work.

6. INSPECT each job, taking care to point out methods and reasons for eliminating unsatisfactory finished products.

Effective Instruction

As you advance in your rating, one of your primary duties will be to instruct your men in the performance of both their technical and military duties. The fundamental principles of leadership, such as "know your men" and "know how to give orders", apply to the teaching-learning situation in which you are dealing with men. Instructing is a very complex skill, and you will have to train yourself to be an effective teacher. The following suggestions will help you:

1. KNOW YOUR SUBJECT. In order to be able to explain the subject matter which you are teaching, you must be thoroughly familiar with it.

2. MAKE THE TASKS MEANINGFUL. This can be accomplished by tying new material in with what the individual already knows, and by showing him how the new material relates to his particular duties.

3. REGULATE THE SIZE OF THE TASK. No one can be expected to learn a lengthy and complicated task all at once. As an instructor, your problem is to break down such a task into component parts which are meaningful units of work. (If a job logically falls into four stages, breaking it down into five or six will increase, rather than decrease, the difficulty of learning.)

4. HAVE YOUR MEN PARTICIPATE. Watching someone do a repair job will be most helpful; however, you will not really learn how to do a job well until you have actually performed it. See that your men spend as much time as possible working on a skilled task. Listen, when necessary, to explanations, and watch demonstrations.

5. REPEAT AND DRILL. Complex acts and skills are not learned without repetition. Drill, however, should be used wisely. It should be spaced so as to avoid monotony and fatigue. Several short periods of drill, spaced over a period of time, are better than one long period.

6. USE MUCH REWARD, LITTLE PUNISHMENT. Correct response should be amply rewarded; incorrect responses

are better rectified by calling attention to the right response than by punishment. In a few cases and for a few people, of course, punishment is necessary, but, in general, praise for good work gets better results than blame for poor work.

Although much of your instruction will be in the form of actual practice, you may be required to lead discussions, deliver lectures, and give demonstrations. If it is consistent with the work to be performed, keep adding new and unfamiliar tasks to the regular duties of your men. You will then have to teach the men the proper way to perform their newly assigned duties. In this way, the men's knowledge of their trade is broadened and your teaching ability is improved.

REWARDS OF ADVANCEMENT

As you advance in your rating, some of the rewards which you will receive are better pay and allowances, additional pay when you retire, and more respect from your superiors as well as from the men you supervise. In addition, you will learn to realize that each time you advance in rating, particularly if you DO YOUR JOB WELL AND TAKE PRIDE IN WHAT YOU DO, you are SERVING YOUR COUNTRY in a more important way. By serving your country most faithfully, you will also have the satisfaction of knowing that you are doing a good job.

SUMMARY

As you advance in rating, you will be required to assume more and more responsibility. As you learn to operate machinery and become proficient in its operation and maintenance, you will be called upon to impart your knowledge to lower rated men and strikers. Therefore, you must become a leader of men, a supervisor and an instructor. If you hope to receive the respect of your men and of your supervisor, you must be able to do the work required of your rate, and to do it in a skillful manner. This accomplishment requires hard work and study,

therefore, you should use the available written training material and take advantage of every opportunity to gain practical experience.

QUIZ

1. The requirements that you must meet before you can become an EN 2 are set forth in which publication?
2. What service rating covers the entire field of Engineman responsibilities during normal peacetime operations?
3. What is the training mission of the peacetime Navy?
4. What is the basic reference on military requirements?
5. In supervising a job, why should you check the progress of the job in the early stages?
6. When instructing men on how to perform a given task, how can you make the task meaningful?
7. When instructing men, why are several short periods of drill, spaced over a period of time better than one long period?

CHAPTER 2

STARTING SYSTEMS

The qualifications for advancement in rating require you to know the purpose and principles of operation of starting systems used with engines. The two methods generally employed for starting modern Navy Diesel engines are: (1) electrical starting for small engines, and (2) compressed air starting for medium-sized and large engines. (In some installations, however, large engines are also started electrically.)

Before proceeding with a discussion of the purpose and principles of operation of electrical and air starting systems, it is most important to know the requirements for starting modern Diesel engines.

REQUIREMENTS FOR STARTING

In order to start a Diesel engine, the crankshaft must be turned over by some outside means so that the air in the cylinder, at the top center, is compressed to such a temperature and pressure that fuel injected by the injection system will ignite and produce a power stroke.

Sufficient Speed

The first requirement for starting a Diesel engine is to turn it over with sufficient speed. If the engine is turned over very slowly, the unavoidable small leaks past the piston rings, and also through the intake and exhaust valves, will allow some of the air to escape during the

compression stroke. Thus, at the end of the stroke, the cylinder pressure, and consequently the temperature, may not be high enough to ignite the injected fuel. In addition, a heat loss from the compressed air to the metal walls of the compression space is greater at low speeds when the duration of the compression stroke is longer; this further lowers the temperature of the air. Therefore, there is a minimum speed which the engine must attain before ignition will occur and the engine starts firing.

The starting speed depends upon the type and size of the engine, its condition, and the temperature of the surrounding air. In some engines the starting speed varies from 70–75 rpm, while in other small engines it may be as high as 250 or even 300 rpm. There is no definite relationship between the starting and operating speed of an engine. However, all other conditions being equal, an engine starts at a lower speed when it is in its best operating condition, has well-seated piston rings and valves, correct timing, and when there is no excessive friction in the engine or in the engine-driven auxiliaries.

Correct Compression Ratio

The second important requirement for starting a Diesel engine is a correct compression ratio. If the compression ratio is not sufficiently high, the final temperature and pressure of the compressed air charge again will not be that required for ignition. A new engine, naturally, has the correct compression ratio. However, the wearing of the bearings may lower the piston position and the compression ratio. In addition, a late closing of the intake valves, caused by incorrect take-up of wear in the valve mechanism, or some other error in the valve timing, may decrease the effective compression ratio.

ELECTRICAL STARTING SYSTEMS

The electrical starting systems used with Navy Diesel engines are much like the starting systems on automobiles, except that many of the starting systems of naval in-

stallations are of the ungrounded type. However, Diesel engines are generally larger than automobile (gasoline) engines and require additional power to be turned over. In general, the power required to first turn the crankshaft of a cold Diesel engine and then bring it up to starting speed is slightly less than 10 percent of its rated output; in some cases it may be as much as 20 percent, especially with small engines. (With large engines, it is about 3 percent of the rated output.)

Electrical starting systems use direct current because the electrical energy in this form can be stored in batteries and drawn upon when needed for starting, after which it can be replenished by recharging with an engine-driven generator.

The main components of the electrical starting system are the storage battery, the starting motor, the generator, and the control devices. (The generator and regulators are not used directly in starting the engine, but their primary purpose is to keep the batteries charged up to run the starting motor. Therefore, they are discussed in this chapter as part of the starting system.)

Storage Batteries

Since the storage battery is the source of electrical energy for the starting motor of Diesel and gasoline engines, you should be familiar with the basic principles of the battery. The construction and principles of operation of a storage battery are covered in Chapter 2 of the Navy Training Course, *Basic Electricity,* NavPers 10086. Additional information concerning the operation of batteries, as well as the maintenance factors, can be obtained from either the manufacturer's instructions or Chapter 62, Section II, of BuShips *Manual.*

Although Electrician's Mates are responsible for the care of batteries, you should be familiar with the factors which affect the operation of storage batteries. When working with engine-starting batteries, the most common troubles you will encounter are as follows: DEAD BATTERY,

LOW ELECTROLYTE LEVEL, LOOSE CONNECTIONS, CORROSION OF TERMINALS. The causes, as well as the remedies, for these troubles are discussed in the paragraphs which follow.

If the starting motor fails to turn when the starter switch has been closed, the probable trouble is a DEAD BATTERY. This symptom alone does not indicate that the battery is dead. If it is dead, a voltmeter placed across the battery terminals will read abnormally low. In addition, the specific gravity reading will be low (about 1.060). Such a failure, generally preceded by a gradual decline in the strength of the battery, is indicated by the engine turning more and more slowly during cranking.

The battery does not have to be completely dead to cause difficulty in starting the engine. Starting becomes increasingly difficult as the battery gets weaker and the cranking speed is lowered. If the battery is *too weak to crank an engine* at normal starting rpm, the engine may fail to start or will not start quickly. Leakage of air past worn rings, or leaky valves, will prevent building up of sufficient compression pressure to ignite the fuel readily.

A common cause for a loss of charge in a starting battery is failure of the engine charging generator to deliver current at a sufficiently high rate to recharge the battery between starts. The same situation may arise with a properly operating charging generator when the engine is started and secured at frequent intervals. In such cases, the charging period is not sufficiently long to keep the battery from running down. In addition, batteries that remain idle for extended periods will gradually lose their charge.

The *generator* voltage regulator, or in some cases a third brush in the generator and a voltage regulator (covered in the section on generators and generator controls), controls the rate at which the generator charges the batteries. It is important that the voltage regulator or the third brush be set for the correct charging rate.

The correct rate of charge is that which will maintain the specific gravity of the battery at approximately 20 points below the normal fully charged gravity. At too low a charging rate, the battery charge will not be replenished between starts, while too high a rate will cause the battery to overheat, gassing of the electrolyte, plate warpage, and rapid deterioration of the battery.

If the plates become sulfated, short circuited, or if the active material is lost, the capacity of the battery will be greatly reduced. In such cases, the battery will become discharged after it has been in use for a short period of time. If such a condition is suspected, the battery should be removed from service and the cells checked. When a bad cell is located, the battery should be removed from service and replaced.

LOSS OF ELECTROLYTE in a battery cell is indicated by an excessive drop in the electrolyte level in comparison with the normal cells. A rapid loss of electrolyte is generally caused by a cracked case, or jar, failure to replace filler caps, and excessive gassing. Small cracks in the side of the battery case will cause the electrolyte to seep out and be lost. If cracks appear in the top of the case, the electrolyte will be "splashed out," causing a rapid decline in the level. (In addition to the loss of electrolyte, the terminals and lugs will be corroded considerably.)

When rapid decline in electrolyte level occurs, the case must be inspected carefully for cracks which may result from rough handling or improper storage. The battery should never be allowed to stand in a totally discharged condition; this increases the danger of freezing, and may result in sulfation of the plates. Likewise, a battery that has been freshly watered should be protected from the cold. If it is not, the water, which at first tends to float on the electrolyte, may freeze and result in breakage of the plates, the separators, and the case.

Failure to replace filler caps, as mentioned earlier, is another cause for a rapid loss of electrolyte. The filler

caps are vented to permit the pressure within the battery to be equalized with the pressure outside the battery. The vent, however, is small enough to prevent the spilling of electrolyte. The vent holes must not be allowed to become plugged, and the filler caps should be screwed tightly in place, while the battery is in service or being charged.

CORROSION OF BATTERY TERMINALS results from pitting, deterioration, or complete disintegration of terminals and lugs. When the terminals are corroded, a greenish-white scale usually covers the terminals, lugs, cables, and the case in the vicinity of the terminals. This scale makes it difficult to loosen the connections, and may result in the burning of the connections. In many cases, corrosion is so severe that it becomes necessary to replace the cables, lugs, and terminals.

Corroded terminals, lugs, and cables should be thoroughly scraped to remove all traces of scale. The surfaces should be washed thoroughly with a solution of baking soda (sodium bicarbonate). Then the battery should be washed with fresh water and dried with compressed air or a cloth. Finally, the terminals, after being cleaned and neutralized, should be coated with petrolatum or cup grease.

In addition, terminals and lugs, if not too badly deteriorated, may be smoothly rounded by scraping with a sharp knife or other tool. Where corrosion is evident, however, it is generally best to replace the lug bolts because corroded bolts may subsequently break and cause the terminals to burn. A corroded and burned terminal is shown in figure 2–1.

Burned terminals may also result from LOOSE CONNECTIONS. If the lug bolts are not properly tightened, there will be only partial contact between the lug and the terminal (fig. 2–2). The small points that do make contact are not sufficiently large in area to carry a heavy current. This results in the overheating and melting of the points. In this case, the total contact area is lessened and conse-

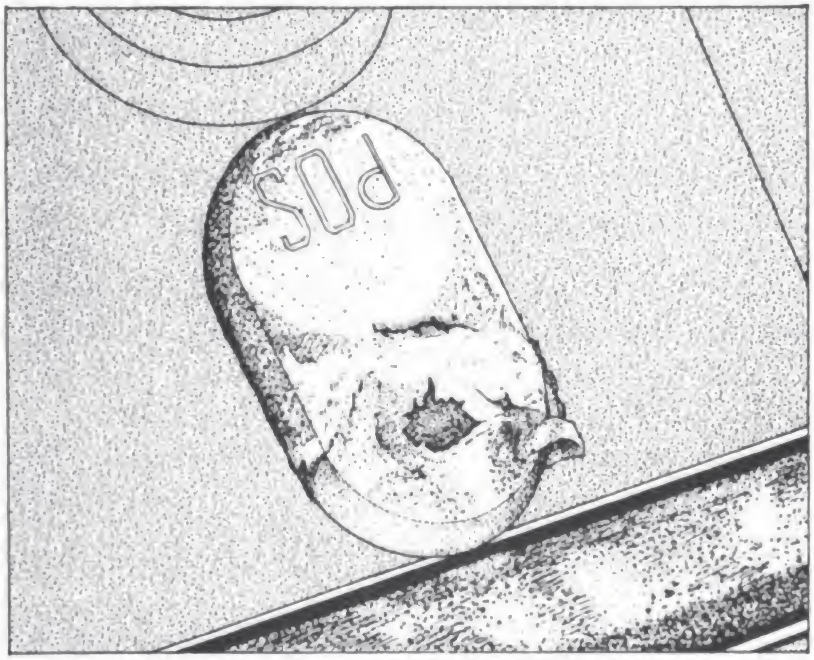


Figure 2–1.—Corroded and burned battery terminal.

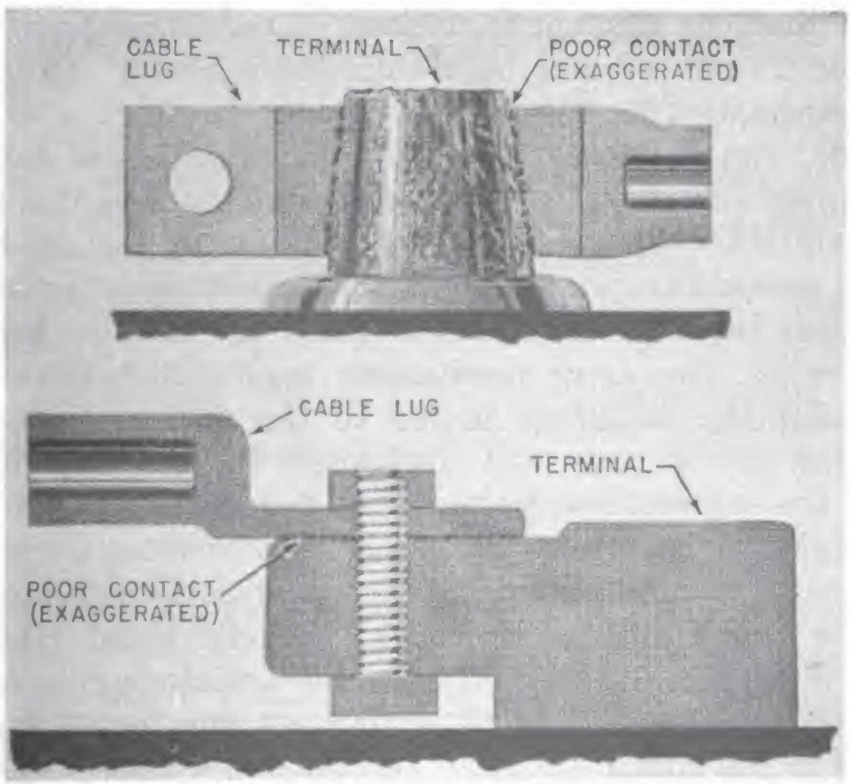


Figure 2–2.—Improperly tightened battery terminal and lug.

quently more overheating and melting follow. Eventually the terminal may be melted to a great extent, and there may not be sufficient contact area to pass the required starting current.

Starting Motors and Drives

The starting motor for both Diesel and gasoline engines operates on the same principles as any electric motor. You should be familiar with the purpose and principles of operation of electric motors, particularly d-c motors, covered in Chapter 11 of *Basic Electricity,* NavPers 10086. Supplementary information is provided in this section on the starting motor circuit and drive mechanisms.

The starting motors for engines are designed to carry extremely heavy loads. In order to carry a heavy load, the starting motor draws a high current (300–550 amperes) which causes the motor to heat up quickly. To avoid overheating the motor, NEVER allow it to run for more than 30 seconds at a time. Then allow it to cool off for 2 or 3 minutes before cranking again.

CRANKING THE ENGINE.—In order to start a Diesel engine, you must turn it over at a fairly rapid rate to obtain sufficient heat of compression to fire the fuel. The starting motor is located near the flywheel, and the drive gear on the starter is arranged so that it can mesh with the teeth on the flywheel when the starting switch is closed. The drive mechanism must function to (1) transmit the cranking power to the engine when the starting motor runs, (2) disconnect the starting motor from the engine immediately after the engine has started, and (3) provide a gear reduction ratio between the starting motor and the engine. (The gear ratio between the driven pinion and the flywheel is usually about 15 to 1. This means that the starting motor armature rotates 15 times as fast as the engine, or at 1500 rpm for an engine speed of 100 rpm.)

The drive mechanism must disengage the pinion from

the flywheel immediately after the engine starts. After the engine starts, its speed may increase rapidly to approximately 1500 rpm. If the starter pinion remained meshed with the flywheel, and also locked with the armature of the starter, at a normal engine speed (1500 rpm), the armature would be spun at a rapid rate—22,500 to 30,000 rpm. At such speeds, the windings would be thrown from the armature and the segments thrown from the commutator.

BENDIX DRIVE MECHANISMS.—One type of driving mechanism used on Navy Diesel engines, such as the General Motors Model 268A engines, is the Bendix drive. This type of drive provides for positive meshing of the drive pinion with the ring gear on the flywheel. Figure 2–3 illustrates a starting motor with a Bendix drive friction-clutch type mechanism.

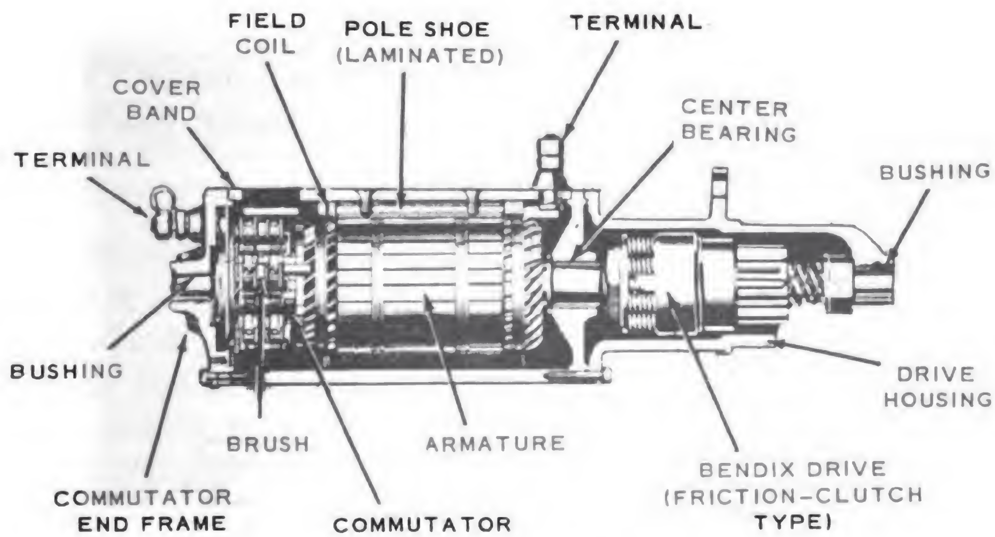


Figure 2–3.—Starting motor with Bendix drive.

The pinion of the Bendix drive is mounted on a spiral threaded sleeve so that when the armature revolves, the threaded sleeve rotates within the pinion, moving the pinion outward, causing it to mesh with the flywheel ring gear, thus cranking the engine.

As soon as the engine runs under its own power, the flywheel drives the Bendix gear at a higher speed than the shaft of the cranking, or starting, motor is rotating. This causes the pinion to be rotated in the opposite direction on the shaft spiral. This automatically disengages the pinion from the flywheel as soon as the engine starts. A friction-clutch mechanism is provided to take the sudden shock when the gear meshes with the flywheel.

Special switches are required to carry heavy current drawn by starting motors. Starting motors equipped with a Bendix drive use a heavy duty MAGNETIC SWITCH (relay switch) to open and close the motor-to-battery circuit, and a hand-operated CONTROL SWITCH to operate the magnetic switch. The control switch is on the instrument panel and may be of the push-button or lever type. The magnetic switch is attached and grounded to the starting motor housing in order to make the heavy current wires as short as possible.

The magnetic switch, shown in figure 2–4, consists of a solenoid mounted on or near the starting motor. Three terminals are used, one to the starting motor, one to the

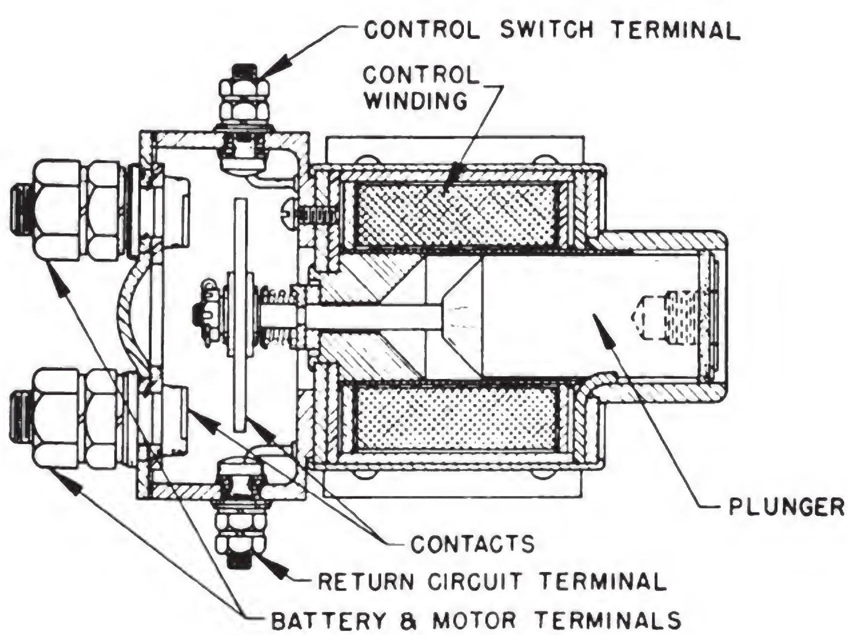


Figure 2–4.—Magnetic switch.

battery, and the third to the switch. When the solenoid is energized by depressing the starting button, or lever, the plunger is drawn into the core and completes the circuit between the battery and the starting motor. A poor switch contact or a shorted solenoid coil will be indicated by excessive heat, after the push button has been depressed for a few seconds. If an opening in the solenoid circuit is suspected, the cap covering the plunger can be removed and the plunger depressed manually.

OPERATING PRECAUTIONS on the Bendix drive must not be overlooked. There are times that the engine starts, throws the pinion out of mesh, and then stops. When the engine is coming to rest, it often rocks back part of a revolution. If at that moment the starter is re-engaged, the drive mechanism may be seriously damaged. Therefore, you must wait several seconds to make certain that the engine is completely stopped before you use the starter again.

In order for the pinion to engage and disengage freely, the sleeve and the pinion threads should be free from grease and dirt. The Bendix drive should be lubricated in accordance with prescribed service instructions.

DYER DRIVE MECHANISMS.—The Dyer shift drive mechanism is installed on the Gray Marine and General Motors series 71 engines used by the Navy. Compared with the Bendix, the advantage of the Dyer shift drive is that the drive pinion meshes with the flywheel ring gear BEFORE the starting motor switch is closed and before the armature begins to rotate. This eliminates clashing of pinion teeth with flywheel ring gear and the possibility of broken or burred teeth on either the engine flywheel or the drive pinion.

A starting motor assembly with the Dyer drive mechanism is illustrated in figure 2–5. Figure 2–6 shows two other views of the Dyer shift drive—a separate drive assembly and a disassembled mechanism. The upper end of the SHIFT LEVER is linked to the SOLENOID SWITCH,

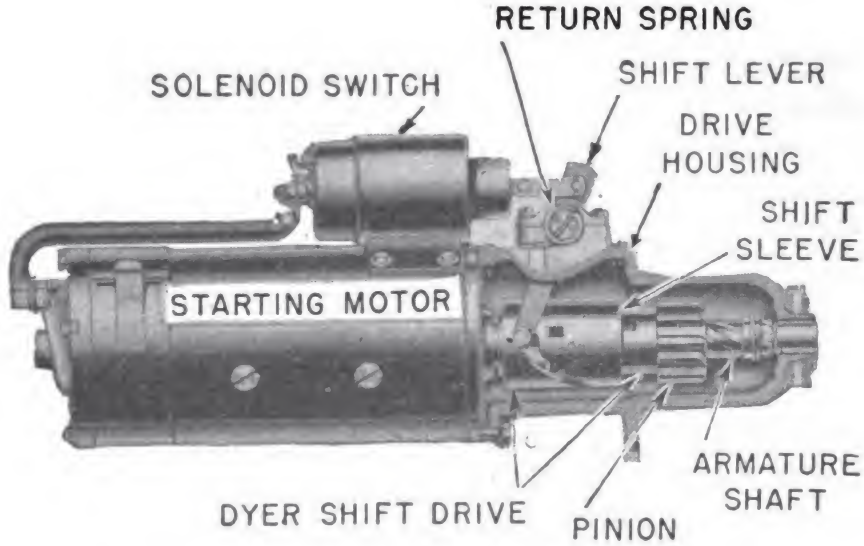


Figure 2–5.—Starting motor with Dyer shift drive.

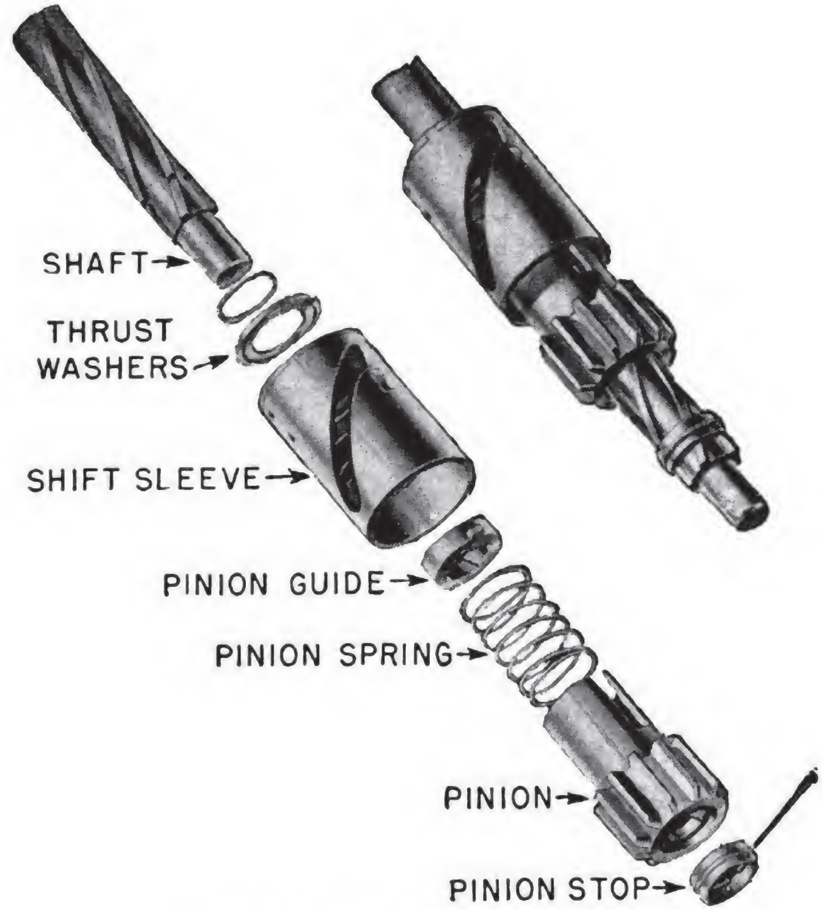


Figure 2–6.—Dyer shift drive mechanism.

housed above the starter. (The action of this switch is described later.) The movement of the shift lever moves the entire drive mechanism axially along the ARMATURE SHAFT toward the flywheel. At the end of this movement, the PINION is meshed with the flywheel and has come to rest against the PINION STOP (fig. 2–6).

When the starting motor armature begins to rotate, the SHIFT SLEEVE is rotated back to its original position, out of the way. The instant the engine starts, the flywheel attempts to spin the pinion faster than the armature is rotating. This causes the PINION and PINION GUIDE to spin back out of mesh, and the pinion guide automatically locks the pinion in the disengaged position.

Starting motors which have the Dyer shift are equipped with a SOLENOID SWITCH. This switch has a plunger linked to the shift lever of the Dyer drive. Movement of the plunger operates the Dyer shift, moving the pinion into mesh with the flywheel. This means that the switch and drive operate together. Figure 2–7 illustrates the solenoid switch and Dyer drive.

At the moment the switch contacts are closed, two things happen. The starting motor begins to operate, and the pull-in coil is shunted out. The pull-in coil is wired across the solenoid contacts so that these contacts serve as a shunt when they are closed. (The pull-in coil draws a comparatively heavy current for a short interval so that the pinion can be engaged.) Shunting out the pull-in coil makes the maximum battery current available for cranking, since the hold-in coil alone draws only a small current.

As soon as cranking begins, the shift sleeve rotates back out of the way, leaving the plunger "in" the solenoid and the cranking circuit closed. When the engine starts, the pinion and the pinion guide spin out of mesh and lock in the demeshed position. The starting motor continues to rotate so long as the starting button is held closed. However, the pinion cannot be re-engaged until the crank-

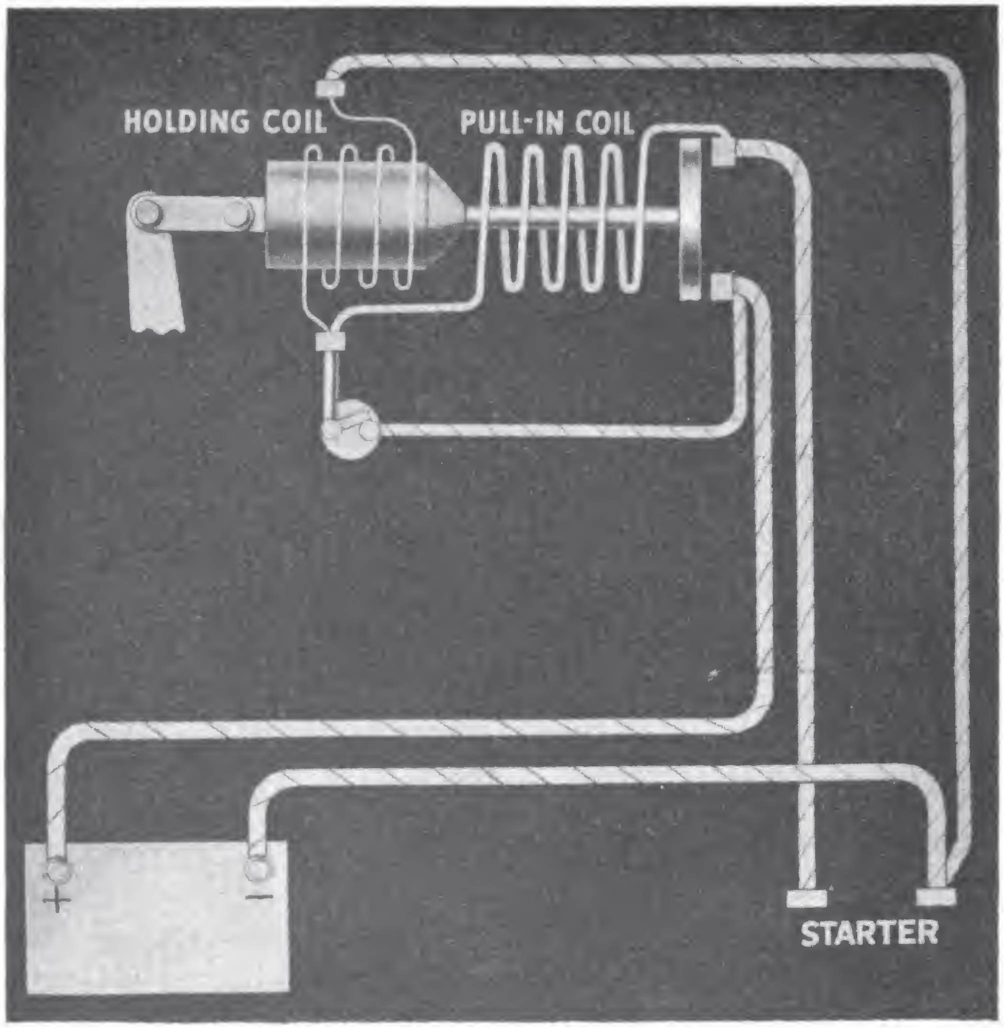


Figure 2–7.—Solenoid switch and Dyer drive.

ing circuit is opened and the plunger is allowed to return to the "at rest" position.

Four stages of OPERATION OF THE DYER SHIFT drive are shown in figure 2–8. In A, the mechanism is in the "at rest" position (as it is shown in fig. 2–5). In B, the starter control switch has been closed and the solenoid switch is pulling the plunger in and beginning to shift the pinion toward the flywheel. In C, the pinion is fully engaged with the flywheel, but the armature has not yet begun to rotate. In D, the starting motor armature is rotating, and the shift sleeve has returned to the "at rest" position. The pinion is driving the flywheel, cranking the engine.

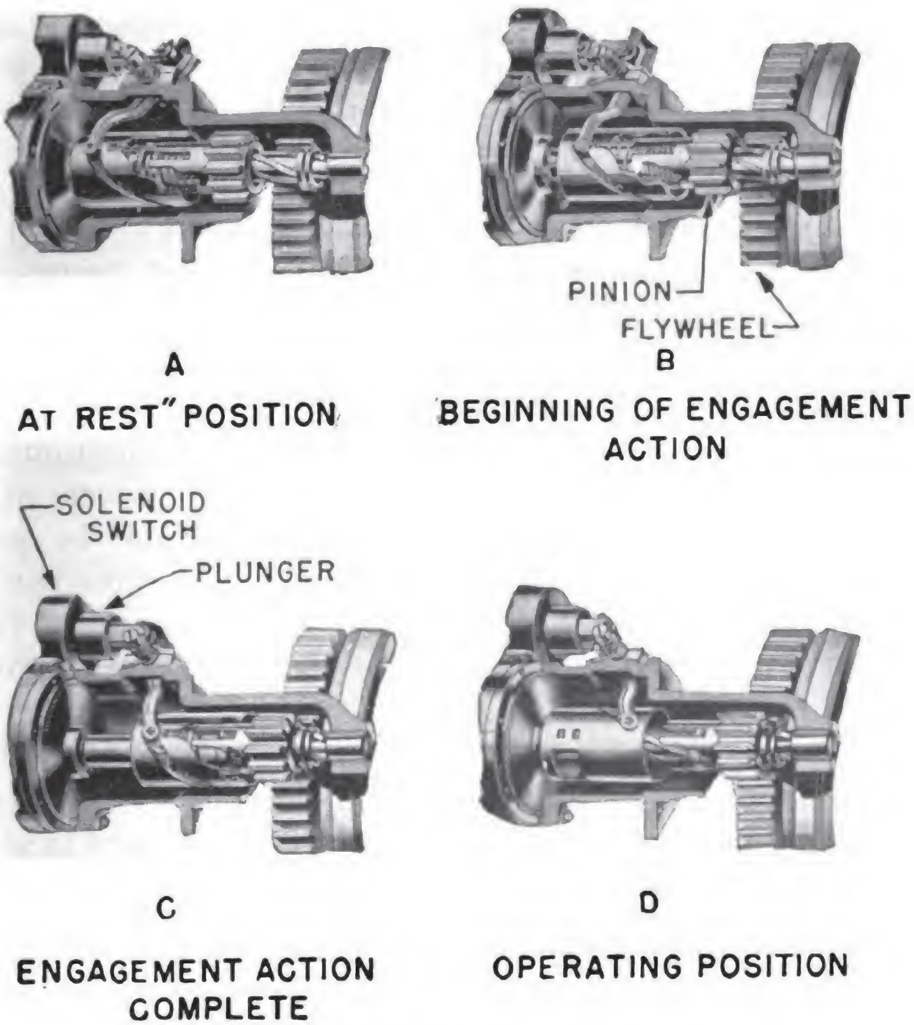


Figure 2–8.—Dyer drive operation.

MAINTENANCE OF STARTING MOTORS.—Periodic inspection and good maintenance will minimize service interruptions. It is best to inspect the cranking motor at the time of each engine oil change. Cranking motors should be lubricated in accordance with the manufacturer's instructions for the specific installation. For example, lubrication instructions for Gray Marine Diesel SIX–D427 engines generally require oiling of the cranking motor every 150 hours of engine operation. A more accurate instruction is to put 2 or 3 drops of engine lubricating oil in the oilers on the cranking motor about every hundred times the engine is cranked. There is a bearing at each end, lubricated by an oil wick. If the bearings

appear to run dry before the engine has been cranked one hundred times, lubricate more frequently. If oil gets on the brushes or commutator, clean the brushes, the holders, and the commutator.

Generators and Generator Controls

In order to qualify as an EN 2, you must know the purpose and principles of operation of small d-c generators which serve to charge the engine-starting batteries. The construction, characteristics, and principles of operation of d-c generators (series, shunt, and compound) are fully covered in Chapter 10 of *Basic Electricity*, NavPers 10086. Supplementary information is provided in this section on the operation of d-c generators and regulating devices. Before proceeding with this section, it probably will be best for you to review Chapter 10 of *Basic Electricity*, NavPers 10086.

D. C. Generators. A typical d-c generator, illustrated in figure 2–9, consists of three main parts, the ARMATURE, the FIELD COILS, and the BRUSHES. The armature is supported on ball bearings, and the field coil windings create a magnetic field through which the armature windings

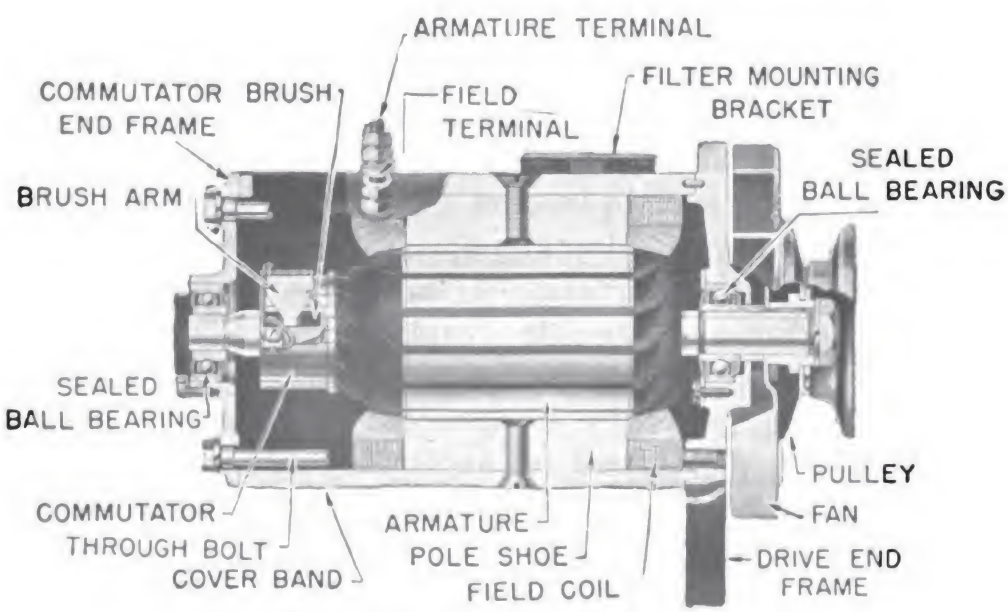


Figure 2–9.—Typical d-c generator.

are rotated. This induces a voltage in the armature windings. The current driven by the induced voltage is circulated through the commutator and carried by the brushes to the external circuit. Part of the armature current is forced through the field winding to increase and maintain the magnetic strength.

The battery charging generator is self exciting; that is it builds its own field strength as the speed of the generator increases. This requires that the field poles always retain a small amount of permanent magnetism, known as residual magnetism. (Battery charging generators are usually of the third brush type or of the shunt types.)

CONTROL DEVICES.—The control units for generators are usually composed of three separate sections: *cutout relay, voltage control,* and *current regulator.* In general, the generators incorporating these sections are shunt wound (the field is in parallel with the armature circuit). In addition, the field exciting voltage is often taken from the commutator by a *third brush* which is adjustable as far as its position is concerned. (Other generators use the full armature voltage, and control the basic charging rate by means of variable series resistance placed in the field circuit by the regulator.) Detailed information concerning the reverse cutout relay and generator output regulation is given in the paragraphs which follow.

CUTOUT RELAY.—The purpose of this control device is to open and close the circuit between the generator and the battery. The relay consists of a magnetic switch which closes the generator-to-battery circuit when the generator is running at charging speeds. However, at slow speeds, when the generator output falls below that of the battery, the current reverses its direction and de-energizes the magnetic relay switch which automatically opens the circuit. This prevents the battery from discharging back through the generator.

The cutout relay (fig. 2–10) has two solenoid windings around an iron core. The current winding consists of

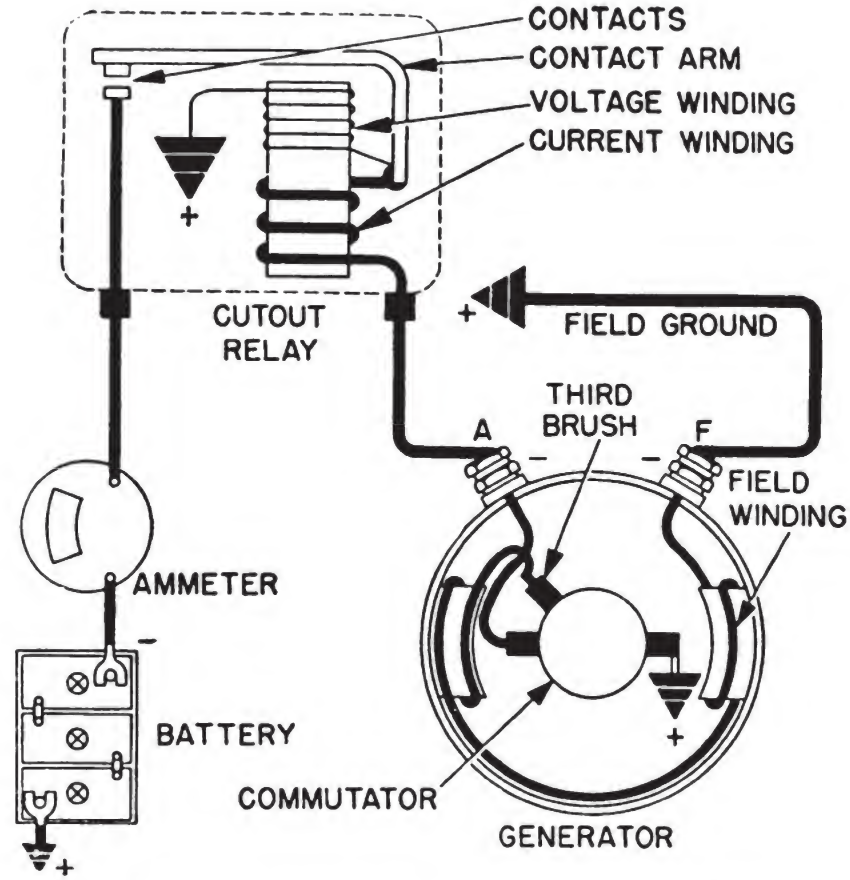


Figure 2–10.—Third brush generator and cutout relay.

a few turns of heavy wire in series with the generator-to-battery circuit. All the generator output must pass through the current winding. The voltage winding consists of many turns of fine wire shunted across the generator. The generator voltage is impressed on the voltage winding at all times. A flat steel contact arm (armature) above the solenoid core is held away from the core by spring tension. A contact point on the arm mates with a stationary contact which is connected through wiring to the battery.

When the generator begins to operate, voltage builds up and forces current through the voltage winding. This creates a magnetic field in the solenoid core. When the voltage reaches the value for which the relay is set—a voltage greater than battery voltage—the magnetism is strong enough to overcome the spring tension of the

contact arm. The arm is then pulled toward the solenoid, closing the contacts and completing the generator-to-battery circuit. Current now flows from the generator to the battery, passing through the current winding in the right direction to add to the magnetism holding the contacts closed.

As soon as the generator operates at a slow speed and the generator voltage is less than the battery voltage, the current reverses and starts to flow from the battery back through the generator. This reverses the direction of current flow in the current winding, but not in the voltage winding. The same side of the voltage winding is always connected to ground, and current always flows through it in the same direction. When the current reverses in the current winding, its magnetic field reverses and bucks the magnetic field of the voltage winding. The resulting magnetic field is too weak to hold the contact arm, and the spring tension breaks the contact. This interrupts the battery-to-generator circuit and prevents draining the battery through the generator.

GENERATOR OUTPUT REGULATION.—It is always necessary to regulate the output of a shunt-wound generator. If the output is excessive, the battery will be overcharged and damaged, and other electrical equipment in the line may be burned out or damaged.

The simplest regulating device is the THIRD BRUSH, illustrated in figure 2–10. This type of regulating device may be found on small engines, such as the Navy type DA. The third brush generator has two main brushes located opposite each other, often at the points of maximum voltage. The voltage across the two main brushes is governed both by the generator speed and the strength of the magnetic field around the armature. In turn, the strength of the magnetic field depends upon the amount of current passing through the field windings.

The current for the field windings is picked up by the third brush, and sent through the windings to ground. The third brush is placed between the two main brushes;

therefore, it picks up less than the maximum available voltage. Moving the third brush toward the nearest main brush increases the field voltage and current. This results in an increase of the strength of the magnetic field, causing a higher generator output. When the third brush is moved in the other direction, the field voltage and current are decreased, and the generator output is reduced. (The third brush is located so that shifting it toward the nearest main brush will move it in the direction of commutator rotation.)

The third brush alone is not a very satisfactory regulator. With a given brush setting, the generator output is small at low engine speeds, increases to a maximum at medium speed, and decreases again at high engine speeds. For greater efficiency, a voltage regulator is added to the third brush generator to smooth out this variation.

The THIRD BRUSH GENERATOR AND VOLTAGE REGULATOR, illustrated in figure 2–11, is generally installed in the Navy type DB and DD power boat engines. The generator-cutout relay-battery system (fig. 2–11) is the same as that shown in figure 2–10, which you just studied. (Since the voltage regulator is similar to the cutout relay, make certain that you understand the operation of the cutout relay.)

The voltage regulator shown in figure 2–11 (vibrating voltage regulator) is a magnetic switch with two windings around an iron core and a contact arm above the core. The voltage winding (V. W.) has many turns of fine wire. It is shunted across the generator-to-battery circuit so that line voltage is impressed on it at all times. The current winding (C. W.) which has only a few turns of heavy wire, carries the generator field current to ground when the regulator contacts are closed. When the regulator is not operating (fig. 2–11), spring tension holds the contacts together.

When the generator begins to operate, the cutout relay contacts are closed and current flows to the battery,

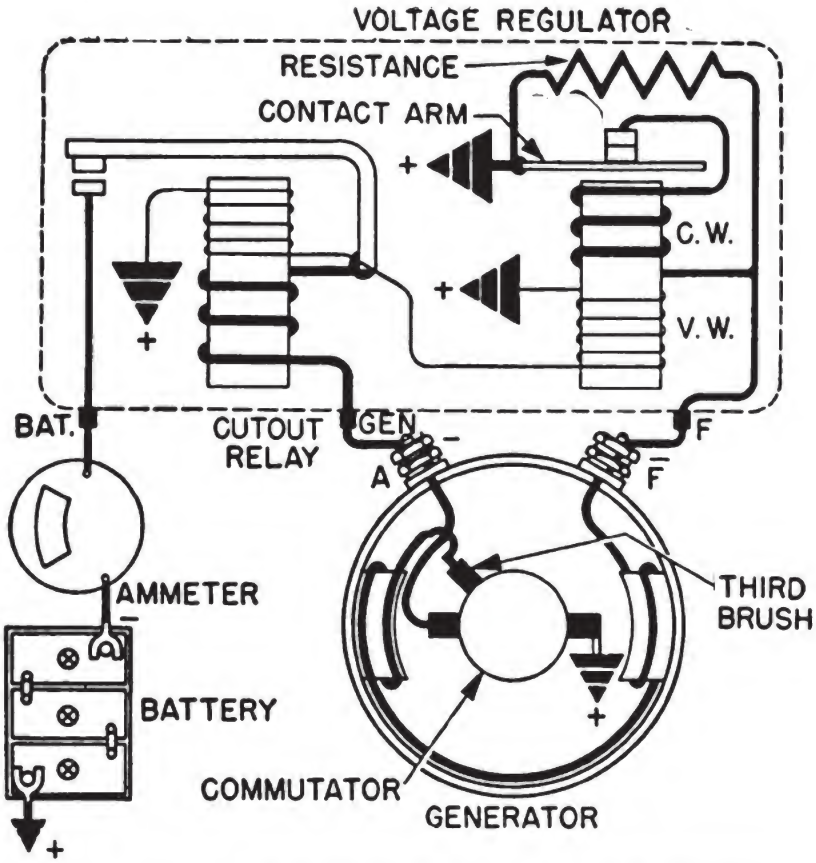


Figure 2–11.—Third brush generator and voltage regulator.

charging it. As the battery approaches a charged condition, the battery and line voltages increase. This increased voltage sends additional current through the voltage winding of the regulator solenoid, increasing the magnetism in the solenoid. When the voltage reaches the value for which the regulator is set, the magnetism of the voltage winding, plus the magnetism of the current winding becomes strong enough to overcome the spring tension of the contact arm. The arm is pulled down toward the core, separating the contact points.

The instant the points separate, all the field current has to go through the resistance, to ground. This immediately cuts down the generator voltage and output. However, as soon as the points separate and field current stops flowing through the current winding, the magnetic field of the winding collapses. In addition, the reduced

voltage in the circuit weakens the magnetic field of the voltage winding in the regulator. The result is that the total magnetic field of the regulator solenoid quickly falls too low to hold the contact arm down. The contact arm springs up again, and the contact points close.

As soon as the points close, the generator field is directly grounded. This permits the generator voltage and output to increase again. The higher voltage strengthens the magnetic field of the voltage winding. At the same time, magnetism is again built up in the current winding. The total magnetism becomes strong enough to open the contacts again, sending the field current through the resistance.

The complete cycle of the regulator windings takes place 50 to 200 times a second, and the generator voltage is held at a safe level, preventing damage from a high voltage.

Most modern d-c generators, however, do not have the third brush. (All the Gray Marine and General Motors series 71 engines have a shunt generator with CUTOUT RELAY, CURRENT REGULATOR, and VOLTAGE REGULATOR.) A typical generator control unit, shown in figure 2–12, illustrates the principles of combined CURRENT and VOLTAGE REGULATORS.

The purpose of the current regulator is to limit the amount of current that the generator can produce; this prevents overloading of the generator. The current regulator has a single current winding connected into the generator-to-battery circuit so that the entire generator output flows through it. The contact arm above the current regulator core is held up with the contacts closed when the regulator is not operating.

When the generator output (through the A terminal and the GEN connection) reaches the level for which the current regulator is set, the magnetism of the current regulator winding overcomes the spring tension holding the contact arm up. The contact arm is pulled down and the points separated. Breaking this contact in the cur-

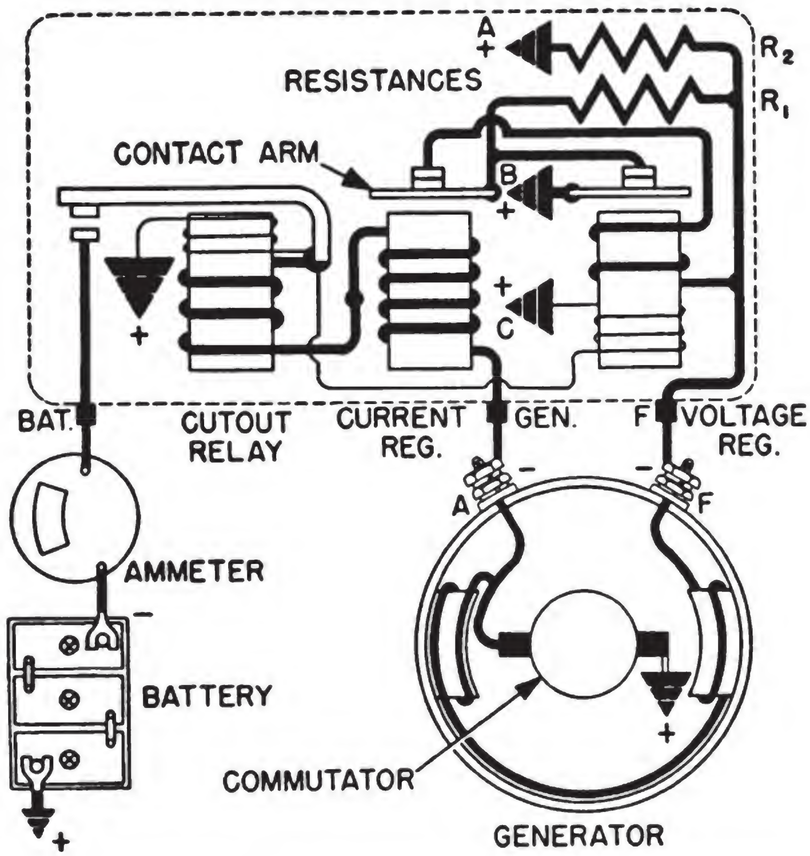


Figure 2–12.—Shunt generator with current and voltage regulators.

rent regulator makes the generator field current (through terminal *F* and connection *F*) take a new path. Instead of passing through the voltage regulator and directly to ground at *B*, the field current must flow through the parallel resistances R_1 and R_2 before reaching ground.

The resistances lower the field current and this cuts down the generator output. The lowered generator output through the current regulator winding reduces the strength of the magnetic field in the regulator and the contact arm is released. The points close, directly grounding the generator field again, and the output increases. This cycle of the current regulator is repeated 50 to 200 times a second, limiting the generator output to a safe level.

When the current and voltage regulators are used on

an engine, only one of them can operate at a time—both never operate at the same time. If the load requirements are heavy and the battery is low, the line voltage will be low and the voltage regulator does not operate. Under these conditions, the generator output can increase until it reaches the level at which the current regulator is set. Then the current regulator operates in the way just described, protecting the generator from overload.

If the load is reduced, or if the battery begins to come up to charge, the line voltage will increase to the point where the voltage regulator begins to operate. When this happens, the generator output through the current regulator winding is too low to operate the current regulator. The latter unit will stand by ready to operate when the line voltage drops.

AIR STARTING SYSTEMS

Starting a large Diesel engine requires the expenditure of considerable energy in a relatively short time. One of the simplest methods for storing large quantities of potential energy is by compressing air into tanks. The compressed air may then be used as a source of starting energy by expanding it in the engine cylinders. This requires a starting-valve gear which adds but little extra weight or size to the engine, and is the method generally used on large engines.

The compressed air used for starting can be readily replenished over a long period of time, after the engine has been started, by means of a small compressor which requires only a small amount of power. The compressor may be driven directly from the engine or from a separate power source, such as a small hand-started engine. In addition to the engine-driven compressor, a separately driven air compressor is used with Navy Diesel engines in order to ensure a positive supply of starting energy.

With most air starting systems, the compressed air is admitted to the top of the main engine cylinder, under a pressure ranging from 100 to 400 psi, through special

poppet starting valves mounted in the cylinder head. Some large engines use air pressures up to 600 psi. The starting valves are timed to open when the pistons are in the position corresponding to the start of the normal expansion stroke. The air pressure thus acts on the pistons which turn the engine as rapidly as necessary for starting. When the engine is turning fast enough, the fuel begins to ignite as it is injected and the starting air is cut off.

In engines with 10 or less cylinders, all the cylinders are generally equipped with air starting valves. In 12- and 16-cylinder engines, only one-half of the cylinders have air starting valves. In double-acting engines, an air starting valve is located in each cylinder, but only in one of the cylinder heads, usually in the upper head. All multi-cylinder engines used by the Navy can be started by the air pressure at any position of the crankshaft without barring the engine over. (Two- and three-cylinder engines require barring over.)

Starting Mechanism

Basically, all air starting systems operate similarly and contain the same elements. If you have a thorough knowledge of the mechanism of one air starting system, you should be able to understand the principles of operation of any air starting method used by the Navy. This section describes the system used on the Cooper-Bessemer GSB–8 engine which is made up of two connected systems; the AIR SUPPLY SYSTEM and the ENGINE SYSTEM (fig. 2–13).

The AIR SUPPLY SYSTEM, which includes the air tanks, reducing valves, piping, and other parts located within the engineroom, is not directly attached to the engine.

The ENGINE SYSTEM, which is directly attached to the engine, consists of five major parts: throttle valve, throttle pilot valve, pilot valve, vitalizer, and air starting valves.

AIR SUPPLY SYSTEM.—The air starting system of the

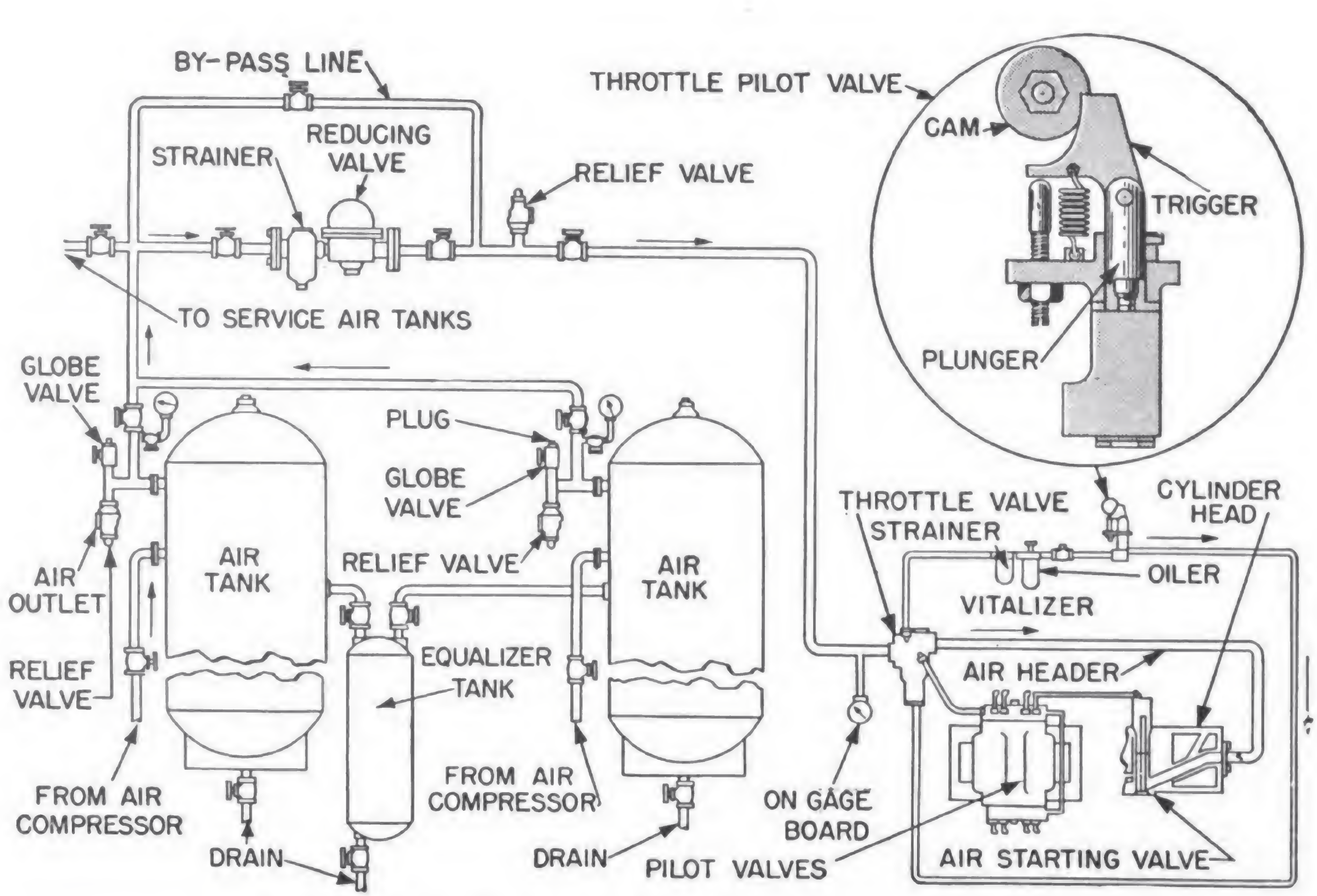


Figure 2–13.—Air starting system of Cooper-Bessemer GSB–8 engine.

Cooper-Bessemer GSB–8 engine is shown in figure 2–13. Compressed air, used to crank the engine, is contained in two AIR STORAGE TANKS, which are generally charged to 600 psi by the ship's compressor. A small EQUALIZER TANK, located between the storage tanks, maintains equal pressures in each of the large air tanks. A drain is provided in the bottom of each tank to permit removal of moisture or dirt accumulations.

A GLOBE VALVE and PRESSURE GAGE are inserted in the line from each tank so that, if necessary, the tanks may be used separately. A spring-loaded RELIEF VALVE is also located in the line from each tank. (These relief valves are poppet type valves, held against their seats by spring tension.) The relief valves are set at a pressure of 660 psi, and will relieve any excess air to the atmosphere.

A single piping and valve system connects the two storage tanks to the air header on the engine. As the air under pressure (600 psi) passes toward the engine header, it flows through a STRAINER and REDUCING VALVE (figs. 2–13 and 2–14). The strainer is placed ahead of

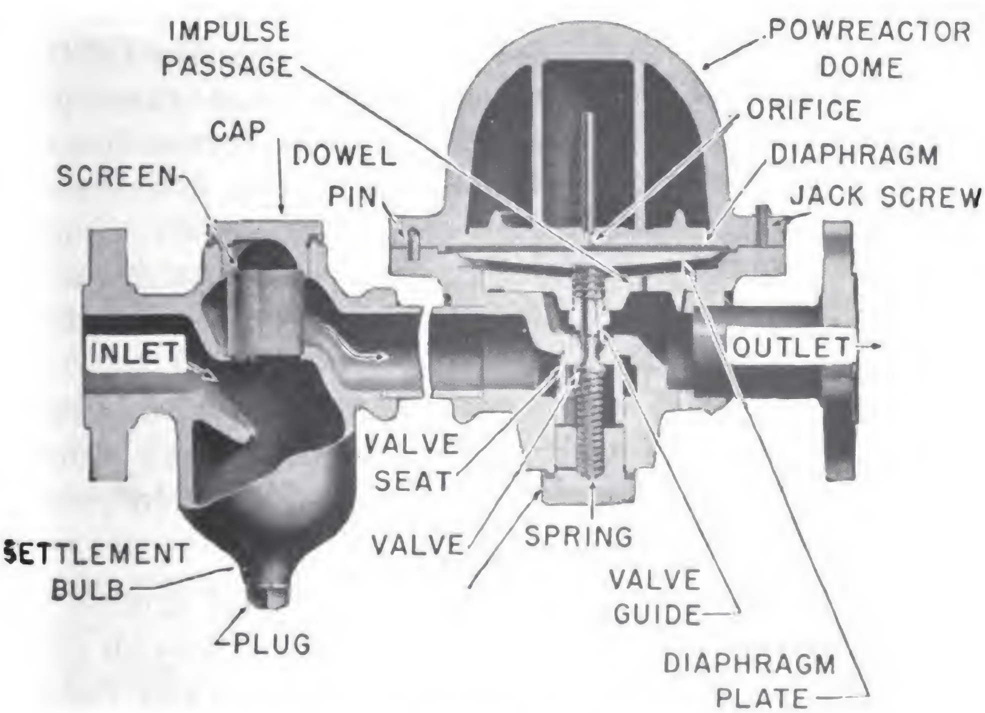


Figure 2–14.—Air strainer and reducing valve.

the reducing valve to protect the valve from pipe scale, moisture, and dirt from the lines. As the air passes through the strainer screen, foreign matter (if present) drops to the SETTLEMENT BULB. By removing the plug (fig. 2–14) periodically, foreign matter can be removed.

The REDUCING VALVE maintains a pressure of 250 psi in the air delivered to the engine, regardless of any fluctuations of air pressure in the storage tanks and any variation in the flow, up to the capacity of the valve. The outlet pressure of the reducing valve depends upon the pressure within the DOME (fig. 2–14). The dome is charged to a pressure slightly higher than the required outlet pressure.

When the reducing valve is in normal operating condition, any drop in the outlet pressure reduces the pressure in the chamber below the DIAPHRAGM PLATE. The air under pressure in the dome passes through the ORIFICE, and forces the DIAPHRAGM down. The diaphragm plate, which rests on the stem of the VALVE, forces the valve open, allowing the incoming air to pass through the VALVE SEAT to the outlet side, where it builds up the outlet pressure again. As a result, air passes through the IMPULSE PASSAGE, and the chamber beneath the diaphragm plate is charged to a higher pressure. This forces the diaphragm upward until the valve is seated, and the discharge pressure is again 250 psi. (WARNING: Do not paint a silver covered dome; silver deflects heat. If painted, heat from the engineroom will expand air in the dome, and cause the air pressure to increase.)

In the event of failure of the reducing valve, a relief valve, set to open at 275 psi, is installed in the reduced pressure (outlet) side of the reducing valve to protect the engine.

The BYPASS LINE (fig. 2–13), connected around the reducing valve and the strainer, may be used as an emergency line, in the event that the reducing valve fails to function. Closing the globe valves on the main line, and

opening the globe valve on the bypass line, cuts out the reducing valve and strainer, and permits starting air to reach the engine through the bypass line. It is important that, when the bypass line is used, the bypass valve be manipulated to control the pressure to the engine; 250 psi should be maintained. The relief valve will protect against excess pressure, however the use of the relief valve to regulate pressure should be avoided.

ENGINE SYSTEM.—The air has now been reduced to the operating pressure and is about ready to enter the engine cylinders. After the air is filtered, it must be timed to enter the cylinders during the power strokes of the pistons, and continue for a limited period in order to permit cranking. (These are the functions of the units directly connected to the engine.)

Starting air is delivered from the storage tanks, through piping, to the THROTTLE VALVE. After leaving the throttle valve, the starting air goes to the VITALIZER, which consists of two units (air strainer and air lubricator), connected in series. The function of the vitalizer is to clean the air further and to add a mist of oil for lubricating the throttle pilot valve. This is accomplished by allowing the air to enter through a fine mesh screen, which removes any remaining dirt or moisture. The high-velocity air then passes through a venturi over an oil bowl. The oil is drawn up and sent through the lines in the form of a mist.

When the air leaves the vitalizer, it enters the THROTTLE PILOT VALVE in the control box, through a globe valve inserted in the pipe line. (The globe valve permits shutting off the starting air at the control box.) Air is also admitted below the throttle pilot valve, and the pressure holds the valve up against the valve seat. At this point, the air remains at a standstill until the engine is to be started.

The cam of the throttle pilot valve is attached to the engine operating shaft so that the engine control handle operates the valve during the first few degrees of travel

from the STOP position. As the cam is rotated clockwise, the cam notch, resting on the trigger, forces the plunger down to open the throttle pilot valve, allowing the air to flow around to the under side of the THROTTLE VALVE. When the engine control handle has passed through the air starting range and is advanced to the point where fuel injection begins, the air supply is stopped. This is accomplished by the action of the trigger moving outward and becoming disengaged from the notch in the cam. Air

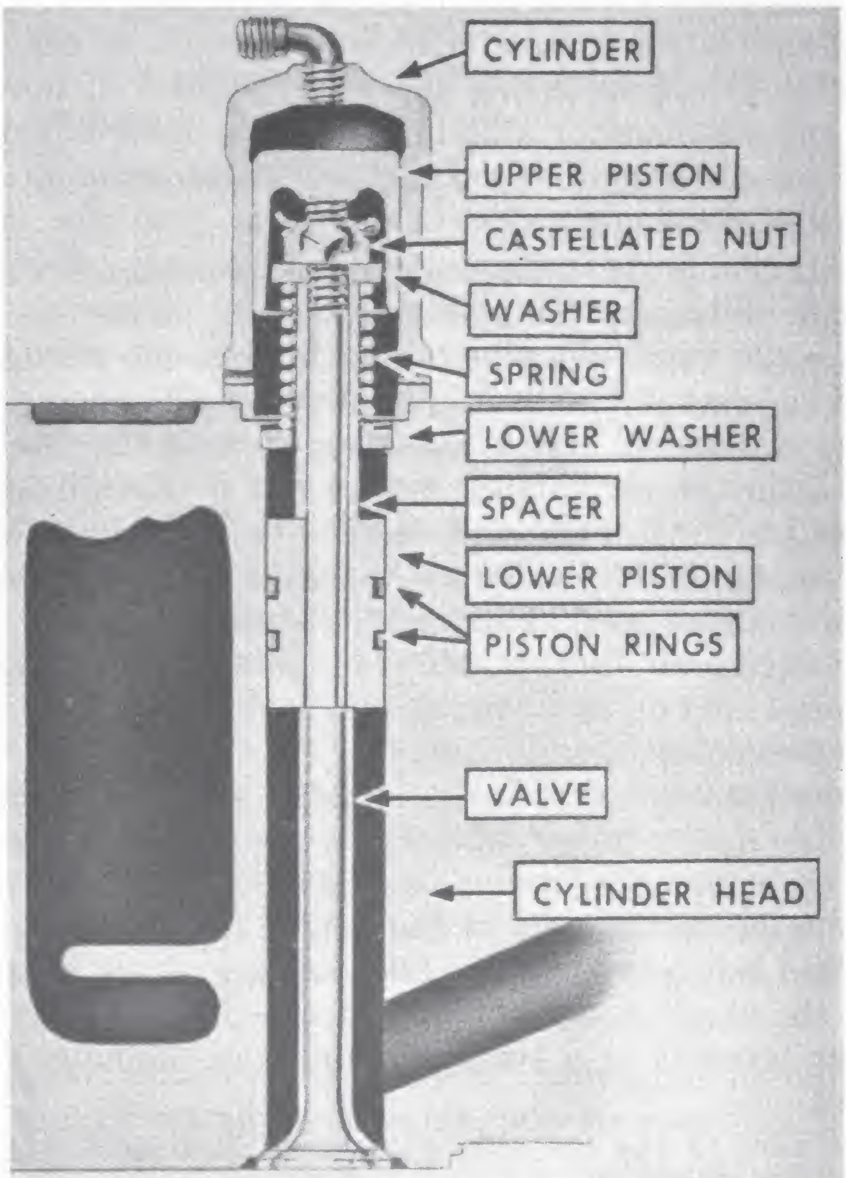


Figure 2–15.—Sectional view of an air starting valve.

pressure then closes the throttle pilot valve by forcing it up against its seat.

When the engine is to be started, the operating shaft is rotated clockwise to force the throttle pilot valve down. This action permits the air to pass directly to the under side of a piston located in the throttle valve. The piston is forced upward to open two valves within the throttle valve. One valve allows the air to enter the AIR HEADER, and the other valve admits air to the PILOT VALVES (figs. 2–14 and 2–17).

The air header is connected to the AIR STARTING VALVE in each cylinder head, as shown in figure 2–13. (Figure 2–15 illustrates a sectional view of an air starting valve.) When an air starting valve is opened, the compressed air forces the piston down in the cylinder, thereby causing the crankshaft to rotate. Operation of the air starting valves is controlled by the pilot valves, which time the air starting valves to open and close at the proper position of each piston.

There are eight valves (one for each cylinder) contained in the PILOT VALVE HOUSING. In figure 2–16, four of the valves are in the upper half of the housing, and four in the lower half. These valves are opened mechanically by a pilot valve camshaft operated by the engine gear train. The compressed air fills the air chamber in the upper and lower PILOT VALVE BODY. The air pressure holds most of the valves against their seats, but because the CAMSHAFT of the pilot valve is always in a position to have at least two valves off their seats, air will be admitted to the air starting valve in those cylinder heads. This opens the starting valve and allows air from the header to enter the engine cylinder.

As the force of the air pushes the pistons down to rotate the camshaft, the engine's gear train operates the pilot valve camshaft. The pilot valves are opened and closed, in the engine firing order, by cams and tappets. When sufficient air has been admitted to make several

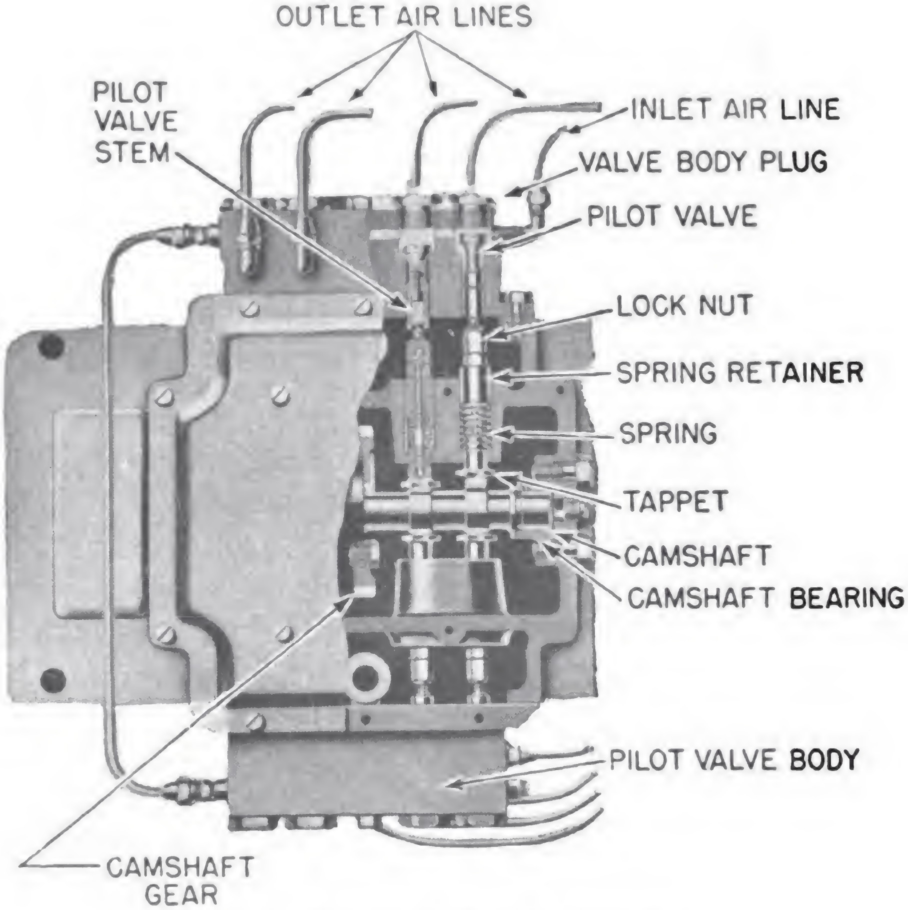


Figure 2–16.—Pilot valve housing.

engine revolutions, the engine control handle is moved into the fuel injection position. This cuts out the starting air at the same time that the engine starts firing.

Reversing of Diesel Engines

Small Diesel engines for boat propulsion are usually connected to the propeller shaft by means of reverse gears. (Reverse gears are discussed in chapter 3 of this training course.) Large Diesel engines for ship propulsion, when driving the propeller mechanically, are usually directly connected to the propeller shaft. Therefore, these engines must be provided with some direct-reversing system for astern operation. For safe maneuvering, the reversing mechanism must be capable of quickly slowing down the engine to a complete stop and then starting it up in the opposite direction. In addition, this must be

accomplished against the action of the propeller, which tends to turn it in the original direction by the motion of the ship through the water.

The only satisfactory method for reversing direct-connected Diesel propulsion engines is by compressed air in conjunction with the air starting system. This is accomplished by changing the timing of the air starting valves so that the compressed air will be admitted to the cylinders to oppose the original direction of rotation. At the same time, the timing of the fuel injection and the intake and exhaust valves is changed to correspond with the new direction of rotation. Thus, as soon as the crankshaft rotation is reversed, the engine will start and operate in the opposite direction.

WARNING: On the Cooper-Bessemer GSB engine, the engine must come to practically a complete stop before the camshaft is shifted. If the camshaft is shifted too fast, changing valve timing, the intake will become exhaust, and the exhaust will become intake, causing the exhaust gases to back up into the intake system.

There are several types of timing mechanisms, however; the function of each is the same; to admit the starting air to the proper cylinder at the proper time. When the Cooper-Bessemer GSB–8 engine is reversed, the pilot valve is automatically timed for the reversed rotation. This is accomplished by means of a spiral gear which meshes with a similar gear on the pilot valve camshaft. When the engine camshaft is moved lengthwise by the air reversing cam, the spiral gear causes a partial rotation of the pilot valve camshaft. This partial rotation adjusts the timing of the pilot valves to admit air to the starting valves in the reversed firing order. (Refer to the timing diagram, figure 2–17. Starting air enters the cylinder when the piston is 18° past top center. When the engine is reversed, the starting air is admitted before the piston reaches top center, and thus forces it down in the reverse direction.)

FOUR-STROKE CYCLE ENGINES.—When a four-stroke

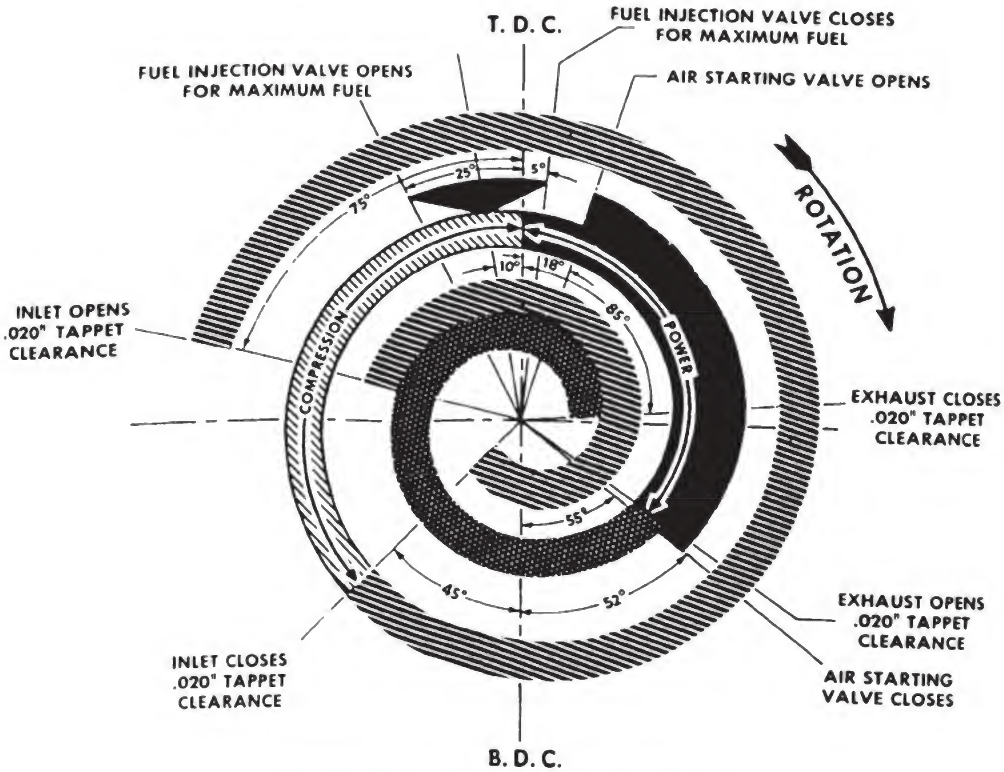


Figure 2–17.—Engine timing diagram.

cycle engine is reversed, the order of the operating strokes is completely changed. The reversing system, therefore, must change both the valve timing with respect to the crankshaft position, as well as the sequence of valve operation. This can be accomplished by using a separate set of cams to operate the valves in each direction of engine rotation. Ahead and astern cams for each valve are provided side by side on the camshaft, and one set of cams is brought into operation by the reversing gear (depending upon the direction of rotation desired). There are two general methods used to bring the second set of cams into position to operate the valve gear for reversing: (1) by sliding the camshaft lengthwise, and (2) by shifting the cam followers.

In case a sliding camshaft is used, the cams are provided with beveled edges or ramps to permit the cam followers to slide over them when the camshaft moves lengthwise. Figure 2–18 illustrates a cam used with a

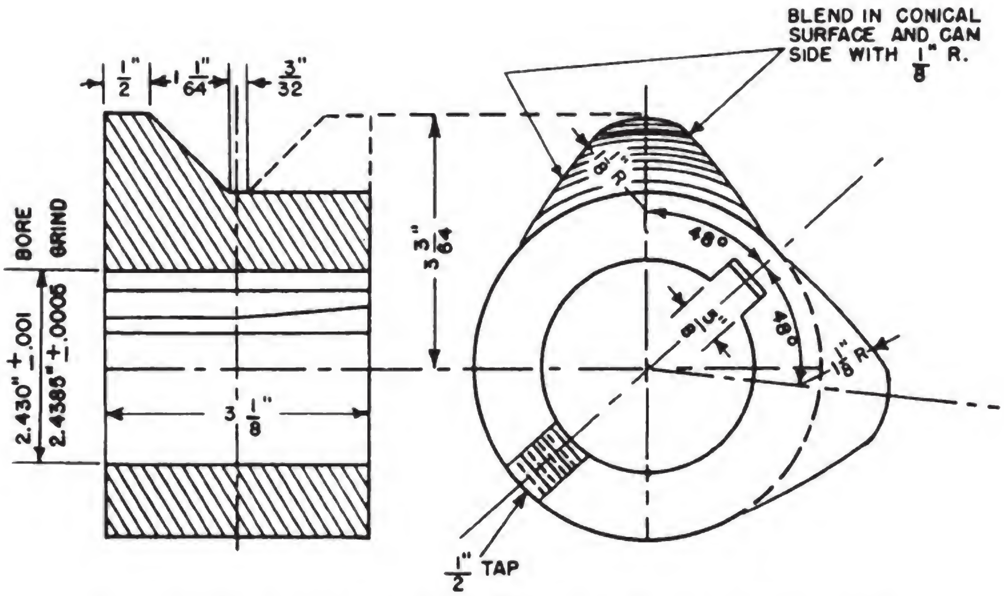


Figure 2–18.—Intake or exhaust cam of a direct-reversible engine.

sliding camshaft. The force to slide the camshaft must be sufficient to overcome the pressure of the valve springs which are compressed when the followers are lifted as the ramps of the cams slide under them. The force required for sliding the camshaft is usually provided by compressed air acting on a piston, connected to the shifting lever.

In order to reduce the force necessary for sliding the camshaft, the cam followers on some engines are lifted clear of the cams while the camshaft slides lengthwise into place, opposite the second set of cams. The cam followers are then returned to their operating position in contact with the second set of cams.

Instead of sliding the camshaft lengthwise, some engines are provided with cam followers which are shifted from contact, with one set of cams to the other, while the camshaft remains in place. One such arrangement uses double roller followers, mounted opposite each set of cams on movable links in the valve gear, as shown in figure 2–19. The valve gear is designed so that one set of rollers will be in contact with the corresponding set of cams for valve operation in one direction. To provide valve operation in the opposite direction, the reverse gear

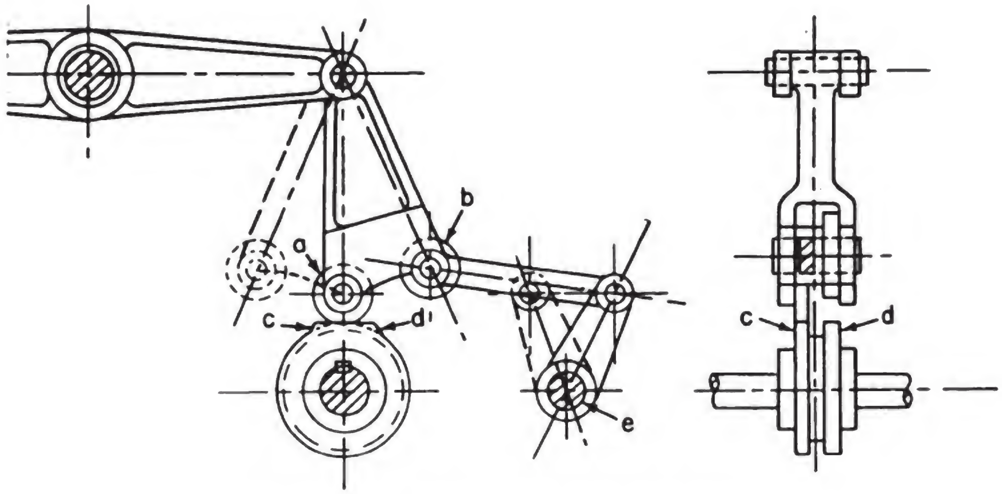


Figure 2–19.—Roller-type reversing gear.

is arranged to swing the movable links in position so that the other set of rollers will contact the second set of cams.

When the cams controlling the timing of the air starting valves and the fuel injector are all mounted on the main valve camshaft, the entire reversing process can be accomplished by providing a second complete set of cams to be used with one of the methods mentioned previously. However, if the air starting and fuel injection systems are operated separately, other methods must be used to reverse the timing.

One method used to change the timing of separately driven air starting and fuel injection systems is to provide symmetrical cams on the individual camshafts which operate these systems. By rotating these camshafts a few degrees with respect to the crankshaft which drives them, when the engine is reversed, the opposite side of the cam will operate the air starting and fuel injection in the correct timing for reverse engine rotation.

When these separate camshafts are driven by means of helical gears, a simple method of rotating them slightly, with respect to the camshaft, is to slide one of the driving gears axially. The number of degrees that the separate camshafts are rotated is controlled by the angle of the gear teeth and the distance the gear moves. This method

may be used when the separate camshaft gears are driven by a sliding main-camshaft helical-drive gear. When the main camshaft and gear slide lengthwise for reversing, the separate camshaft gears are rotated to change the timing of the air starting system and the fuel injection system.

TWO-STROKE CYCLE ENGINES.—While any of the above-mentioned methods for changing the valve timing of a four-stroke engine could be applied to the valve gear of a two-stroke engine, a simpler type of reverse gear can be employed. In the two-stroke engine, the timing of the air starting valves, the fuel injection valves, and the scavenging valves, if used, may be changed merely by rotating the cam followers a few degrees, with respect to the camshaft, as shown in figure 2–20. The valve lift in the astern position is less than in the ahead position

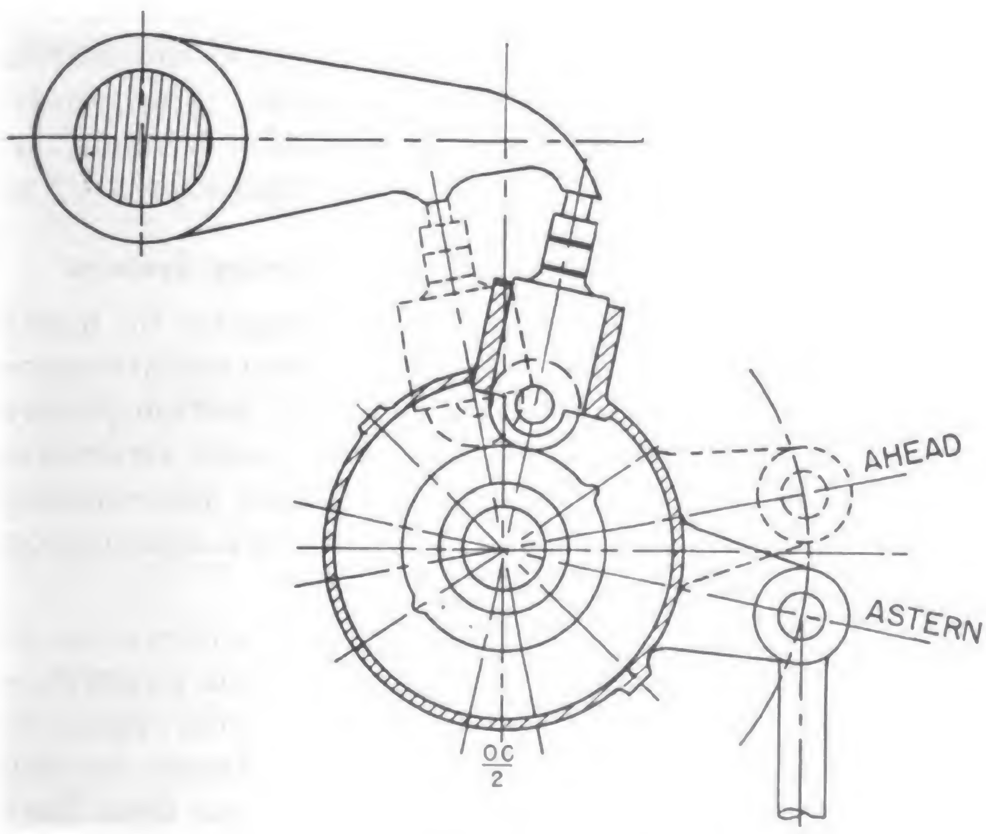


Figure 2–20.—Reverse gear with movable roller.

because of the changed leverage. It is convenient to reduce the reversing angle by one-half, by using a half-speed camshaft and a double-nosed cam.

Where the camshafts are gear-driven from the crankshaft, they may be rotated, with respect to the drive gear, by means of sliding helical gears or splines. When they are chain-driven, the timing of the camshafts, with respect to the crankshaft, is changed by movable idler sprockets which shorten the effective chain on one side while lengthening it on the other side of the drive sprocket.

In an opposed-piston engine, the crankshaft connected to the pistons, which control the exhaust ports, is set ahead of the other crankshaft (connected to the pistons controlling the scavenge parts) by several degrees of rotation when operating in the normal ahead direction. The crankshafts are geared together in this fixed relative position, and when the engine is reversed, the crankshaft controlling the exhaust ports will lag behind the crankshaft controlling the scavenging air ports. This condition is not desirable for best performance, however, it can be tolerated for less than full-power operation astern.

Inspection and Maintenance of Air Starting Systems

For maximum reliability, it is necessary to make periodic inspections and to carry out correct maintenance procedures for air starting systems. This section covers the general instructions pertaining to air tanks, strainers, and valves (throttle, and relief). Detailed information may be obtained from the manufacturer's instruction books.

AIR TANKS.—The air tanks require only a minimum of attention. Drain the moisture and the other impurities from the tanks periodically. Inspect the tanks regularly for corrosion and cleanliness. Check the flange connections, pipe plugs, and handhole cover to be sure they are tight and do not leak. In addition, see that the supporting brackets are securely attached to the bulkhead.

THROTTLE VALVE.—This unit (fig. 2-21) may be inspected and serviced without removing it from the engine. However, if the valve is to be removed, the following procedure must be observed:

1. Disconnect the air line from the throttle valve to the vitalizer.
2. Disconnect the air line from the throttle valve to the throttle pilot valve.
3. Disconnect the air line from the throttle valve to the pilot valve.
4. Disconnect the pipe union between the throttle valve and the air starting header.
5. Unscrew the throttle valve from the air supply piping.

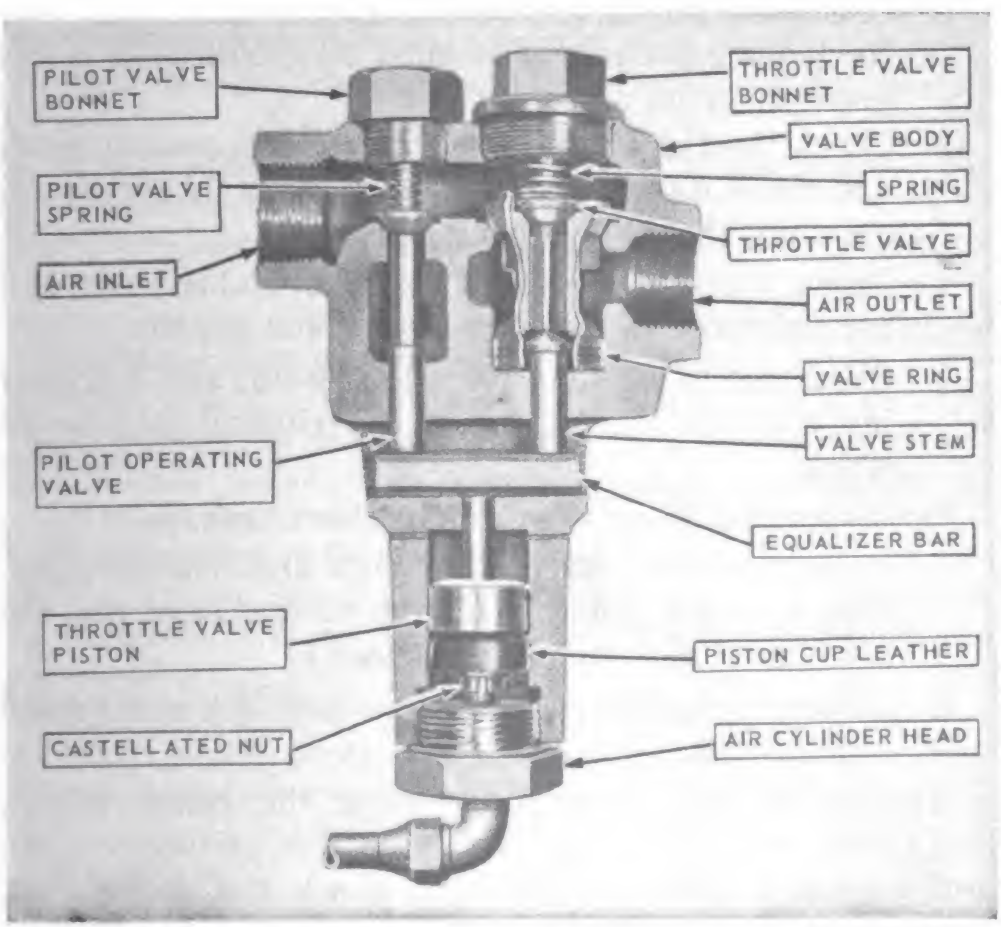


Figure 2–21.—Cutaway view of throttle valve.

6. Remove the pilot valve bonnet, and lift out the pilot operating valve and the spring.
7. Remove the throttle valve bonnet and lift out the air throttle valve, the throttle release valve, the valve stem, and the spring. Handle the valve ring carefully. After the valve stem has been removed, the equalizer bar will be free and can be removed easily.
8. Remove the air cylinder head.
9. Pull out the throttle valve piston assembly, which contains the piston cup leather.

When inspecting the throttle valve, perform the following checks:

1. Check the pilot operating valve for excessive wear on its stem, and for proper seating. If grinding is necessary, a fine grade of grinding compound must be used.
2. Check the air throttle valve for excessive wear and for proper seating. If it must be ground, use a fine grade of grinding compound.
3. Check the throttle release valve for excessive wear, and check its seating with the throttle. If necessary, grinding should be accomplished.
4. Check the throttle valve ring for undue wear and for clearance in the cylinder and the groove.
5. Check the valve stem for undue wear, and for seating with the throttle valve. (Grinding may be required.)
6. Inspect both springs for possible breakage.
7. Inspect the cup leather for cuts and deterioration. (To replace a cup leather, remove the cotter pin, the castellated nuts, and the washers.)
8. Inspect the seats of the valve body for cracks and undue wear.

RELIEF VALVES.—When inspecting the relief valves, check the valve seats and the valves for pitting, cracks, and excessive wear. In addition, check the springs for breakage.

SUMMARY

As an EN 2, you must know the purpose and principles of operation of electrical starting and air starting systems. As far as the electrical starting systems are concerned, you should be familiar with the operating and maintenance instructions for batteries, starting motors, and generators.

All air starting systems operate similarly and contain the same elements. If you have a thorough knowledge of the mechanism of one air starting system, you should be able to understand the principles of operation of any air starting system used by the Navy.

QUIZ

1. What two methods are generally employed for starting modern Navy Diesel engines?
2. What are two requirements for starting a Diesel engine?
3. What are the main components of the electrical starting system?
4. If the starting motor fails to turn when the starter switch has been closed, what is the probable trouble?
5. A rapid loss of electrolyte generally results from what three causes?
6. In order for a drive mechanism to operate satisfactorily, the mechanism must perform what three functions?
7. What type of drive provides for positive meshing of the drive pinion with the ring gear on the flywheel of a starting motor?
8. The drive pinion of which drive mechanism meshes with the flywheel ring gear BEFORE the starting motor switch is closed and before the armature begins to rotate?
9. If a starting motor is equipped with a Dyer drive mechanism, what will occur as soon as the solenoid switch contacts are closed?
10. When is it generally best to inspect the cranking motor?
11. What control device functions to open and close the circuit between the generator and the battery?
12. What is the simplest regulating device used on the Navy type DA engines?
13. Most modern shunt generators are equipped with what type of regulating devices?

14. The air starting system of the Cooper-Bessemer GSB-8 engine consists of what two connected systems?
15. The air storage tanks of the Cooper-Bessemer GSB-8 engine are generally charged to what pressure?
16. What unit of the air starting system, placed ahead of the reducing valve, protects the valve from pipe scale, moisture and dirt?
17. What unit is designed to maintain a pressure of 250 psi in the air delivered to the engine, regardless of any fluctuations of air pressure in the storage tanks?
18. What is the function of the vitalizer of the Cooper-Bessemer GSB-8 engine system?
19. What valves time the air starting valves to open and close at the proper position of each piston?
20. When inspecting the relief valves of an air starting system, what checks must be made?

CHAPTER 3

MECHANICAL AND FLUID DRIVES

The devices used to transmit the power developed by a marine engine to the propeller of a vessel are, in general, clutches, reverse gears, reduction gears, and the related shafting. Before discussing the various types of mechanical and fluid drives, it might be best to briefly review the application of the above-mentioned parts to Navy marine installations.

Clutches, Reverse Gears, and Reduction Gears

Clutches may be used on direct-drive propulsion Navy engines to provide a means of disconnecting the engine from the propeller shaft. In small engines, clutches are usually combined with reverse gears and used for maneuvering the vessel. In large engines, special types of clutches are used to obtain special coupling or control characteristics, and to prevent torsional vibration.

Reverse gears are used on marine engines to reverse the direction of rotation of the propeller shaft, when maneuvering the vessel, without changing the direction of rotation of the engine. They are used principally on relatively small engines. If a high-output engine has a reverse gear, the gear is used for low-speed operation only, and does not have full-load and full-speed capacity. For maneuvering vessels with large direct-propulsion engines, the engines are reversed.

Reduction gears are used to obtain low propeller-shaft speed with a high engine speed. When accomplishing

this, the gears correlate two conflicting requirements of a marine engine installation. These opposing requirements are: (1) for minimum weight and size for a given power output, engines must have a relatively high rotative speed; and (2) for maximum efficiency, propellers must rotate at a relatively low speed, particularly where high thrust capacity is desired.

There are many types of transmissions used by the Navy. This chapter covers, in general, the operation and maintenance of transmissions utilizing the friction, fluid, electromagnetic, and dog-type clutches and couplings which may be found on Navy marine installations. Additional information concerning a particular unit can be obtained from the manufacturer's instruction book, or manual, for that specific installation.

FRICTION CLUTCHES AND GEAR ASSEMBLIES

Friction clutches are commonly used with smaller, high-speed engines, up to 500 hp. However, certain friction clutches, in combination with a jaw-type clutch, are used with engines up to 1400 hp; and pneumatic clutches, with a cylindrical friction surface, with engines up to 2000 hp.

Friction clutches are of two general styles; the DISK and the BAND styles. In addition, friction clutches can be classified into dry and wet types, depending upon whether the friction surfaces operate with or without a lubricant. The designs of both types are similar, except that the wet clutches require a large friction area because of the reduced friction coefficient between the lubricated surfaces. The advantages of wet clutches are smoother operation and less wear of the friction surfaces. Wear results from slippage between the surfaces not only during engagement and disengagement, but also, to a certain extent, during the operation of the mechanism. Some wet-type clutches are filled with oil periodically; in other clutches the oil, being a part of the engine-lubricating system, is circulated continuously. Such a friction clutch incorporates provisions which will prevent worn-

off particles from being carried by the circulating lubricating oil to the bearings, gears, etc.

The friction surfaces are generally constructed of different materials, one being of cast iron or steel; the other is lined with some asbestos-base composition, or sintered iron or bronze for dry clutches, and bronze, cast iron, or steel for wet clutches. Cast-iron surfaces are preferred because of their better bearing qualities and greater resistance to scoring or scuffing. Sintered blocks are made of finely powdered iron or bronze particles, molded in forms to the desired shape, under high temperature and pressure.

As far as engagement of the friction clutches is concerned, the application of force-producing friction can be obtained either by mechanically jamming the friction surfaces together by some toggle-action linkage, or through stiff springs (coil, leaf, or flat-disk type). The operation of friction clutches is covered in the paragraphs which follow.

Twin-Disk Clutch and Gear Mechanism

One of the several types of transmissions used by the Navy is the Gray Marine transmission mechanism, shown in figure 3–1. Gray Marine high-speed Diesel engines are generally equipped with a combination clutch, and reverse and reduction gear unit—all contained in a single housing, at the after end of the engine. A sectional view of this mechanism is shown in figure 3–1.

The CLUTCH ASSEMBLY of the Gray Marine transmission mechanism is contained in the part of the housing nearest the engine (the left end of fig. 3–1). It is a dry-type, TWIN-DISK clutch with two driving disks. Each disk is connected, through shafting, to a separate reduction gear train in the after part of the housing. One disk and reduction train is for reverse rotation of the shaft and propeller, the other disk and reduction train for forward rotation. The forward and reverse gear trains for

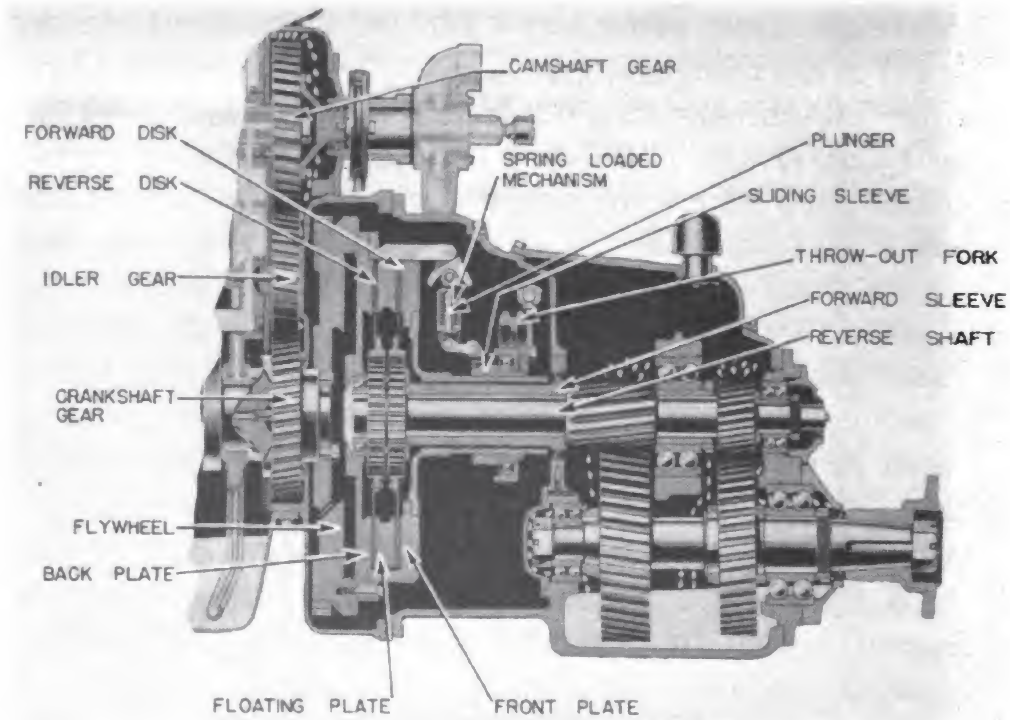


Figure 3–1.—Gray Marine clutch and gears.

Gray Marine engines are illustrated in figure 3–2. By studying both figures 3–1 and 3–2, you will notice that the gear trains are different in the two illustrations, however, the operation of the mechanisms shown is basically the same.

CLUTCH OPERATING LEVER.—Since the gears for forward and reverse rotation of the twin-disk clutch and gear mechanism remain in mesh at all times, there is no shifting of gears. In shifting the mechanism, only the floating plate, located between the forward and reverse disks, is shifted. The shifting mechanism is a SLIDING SLEEVE, which does not rotate, but has a loose sliding fit around the hollow forward shaft. A THROW-OUT FORK (yoke) engages a pair of shifter blocks pinned on either side of the sliding sleeve.

The CLUTCH OPERATING LEVER moves the throw-out fork, which in turn shifts the sliding sleeve lengthwise along the forward shaft. When the operating lever is placed forward, the sliding sleeve is forced backward.

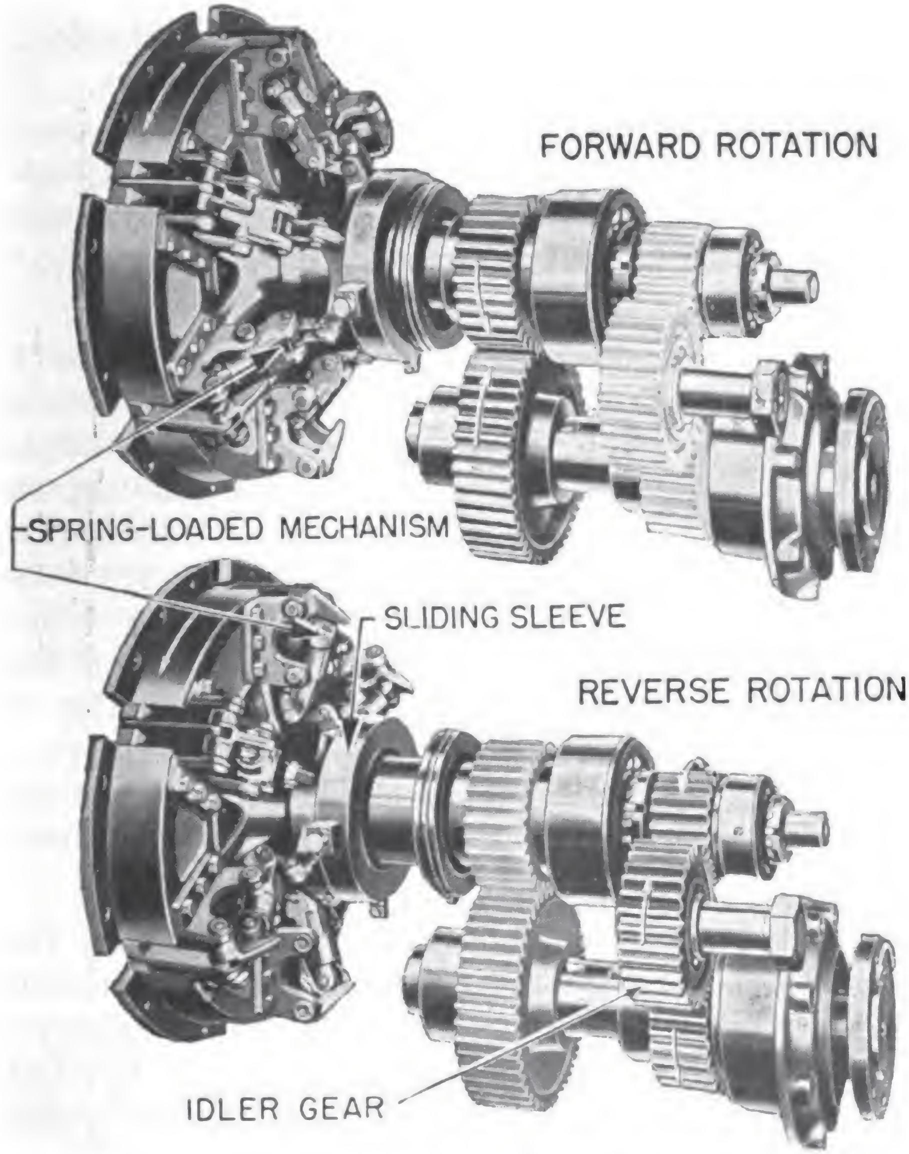


Figure 3–2.—Forward and reverse gear trains for Gray Marine engines.

In this position the linkages of the spring-loaded mechanism pull the floating pressure plate against the forward disk, and cause forward rotation. When the operating lever is pulled back as far as it can go, the sliding sleeve is pushed forward. In this position, the floating pressure plate engages the reverse disk and back plate for reverse rotation.

The clutch has a positive neutral which is set by placing the operating lever in a middle position. Then the

sliding sleeve is also in a middle position, and the floating plate rotates freely between the two clutch disks. (The only control that the operator has is to cause the floating plate to bear heavily against either the forward disk or the reverse disk, or to put the floating plate in the positive neutral position so that it rotates freely between the two disks.)

FORWARD ROTATION.—As mentioned above, the two clutch disks shown in figure 3–1 are separated from each other by the FLOATING PLATE. Let us see what happens when the floating plate presses against the FORWARD DISK. This disk is, in turn, pressed against the FRONT PLATE, which is bolted to and rotates with the ENGINE FLYWHEEL. The friction disk immediately begins to rotate with the front plate at engine speed. The forward disk is keyed to the FORWARD SLEEVE, which is a hollow shaft. The forward-sleeve shaft transmits the rotation to the propeller shaft through the two-gear train, shown in the upper view of figure 3–2. (Notice the arrows which indicate the directions of rotation.)

REVERSE ROTATION.—By causing the FLOATING PLATE to press against the REVERSE DISK, reverse rotation is obtained. In turn, the reverse disk is pressed against the BACK PLATE, which is also bolted to the ENGINE FLYWHEEL (fig. 3–1). At engine speed, the reverse disk begins to rotate with the back plate. The disk is keyed to the solid REVERSE SHAFT, which rotates inside the hollow forward shaft. The reverse shaft transmits the rotation through the three-gear train, shown in the lower view of figure 3–2. Notice the presence of an idler gear, in the reverse-gear train. This gear reverses the direction of the propeller shaft rotation.

LUBRICATION.—The reversing gear unit is lubricated separately from the engine by its own splash system. The oil level of the gear housing should never be kept over the high mark because too much oil will cause overheating of the gear unit. The oil is cooled by air which is blown

through the baffled top cover by the rotating clutch. Grease fittings are installed for bearings not lubricated by the oil. Since this clutch is a dry friction clutch, good judgment should be used when greasing the mechanism. Any grease on the friction plates will cause slippage. To prevent binding caused by rust, clutch parts which are not equipped with grease fittings should be lubricated with light machine oil.

OPERATIONAL ADJUSTMENTS.—Since the spring-loaded clutch-operating mechanism is pressure-set at the factory, it is not necessary to adjust the mechanism. The mechanism is designed to follow up and to compensate for wear on the friction plates. The simplest way to determine when the disks require replacement is to check the position of the plunger in the engaged position. The plunger is permitted to travel a specified amount in accordance with manufacturer's instructions. The gears are keyed to their shafts, mounted on ball bearings in permanently fixed centers, and require no adjustment.

Under normal operating conditions, the life of the clutch can be prolonged by reducing the engine speed to idle before reversing the direction of rotation.

Joe's Double Clutch Reverse Gear

A typical gear mechanism found on many power boats is JOE'S DOUBLE CLUTCH REVERSE GEAR. The installation of a typical Joe's reverse gear and clutch assembly for the Navy type DC engine is shown in figure 3–3. The drive from the engine crankshaft is taken into the clutch and reverse gear housing by an extension of the crankshaft drive gear. The crankshaft rotation is transmitted to the reduction gear shaft through the clutch and the reverse gear unit.

CLUTCH AND REVERSE GEAR ASSEMBLY.—If you could open the clutch and reverse gear housing and watch the REVERSE GEAR DRUM and the REDUCTION GEAR SHAFT while the engine is running, you would observe the following operations:

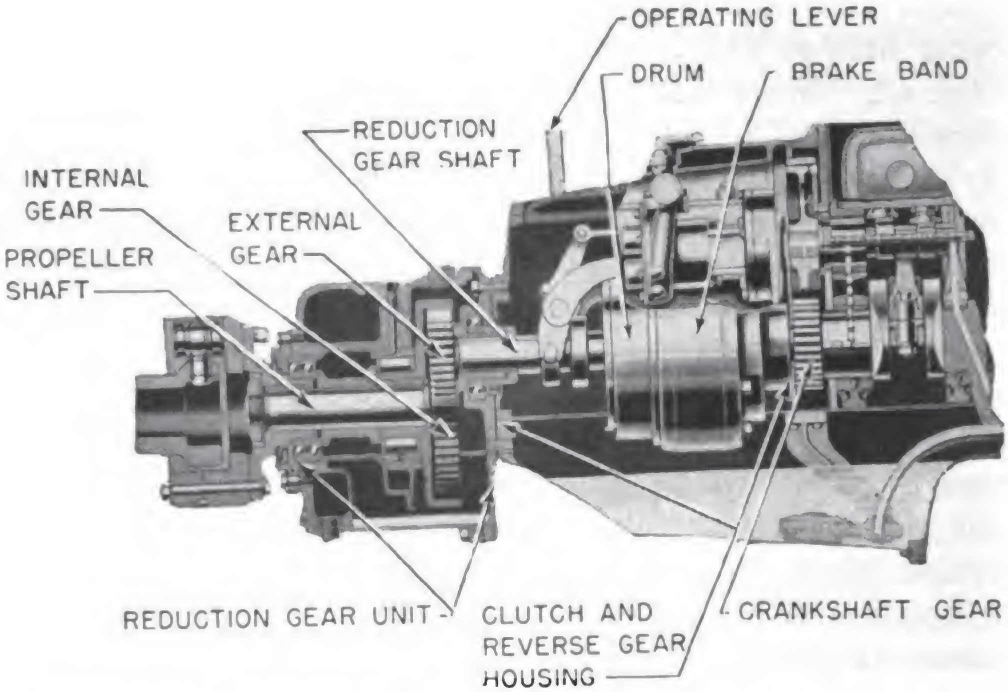


Figure 3–3.—Reverse and reduction gear housings on Navy type DC engine.

When the OPERATING LEVER is thrown forward, the drum and reduction gear shaft rotate in the same direction as the engine crankshaft. This causes FORWARD ROTATION of the propeller.

In the intermediate position of the operating lever, the drum rotates but the reduction gear shaft remains stationary. This is the NEUTRAL setting.

By studying figure 3–4 which shows a cutaway view of Joe's clutch and reverse gear, you will be able to obtain a better understanding of the operation of the mechanism.

Forward rotation is obtained by dual clutch action while reverse rotation is obtained through the operation of the planetary gears. The unit consists of a housing enclosing a split conical clutch and a multi-plate friction clutch and gearing. Additional components include the collar and yoke and an outer brake band with an operating toggle mechanism. Movement of the sliding collar selects the direction of rotation.

FORWARD ROTATION.—When the operating lever is placed in the forward position, the linkage between the

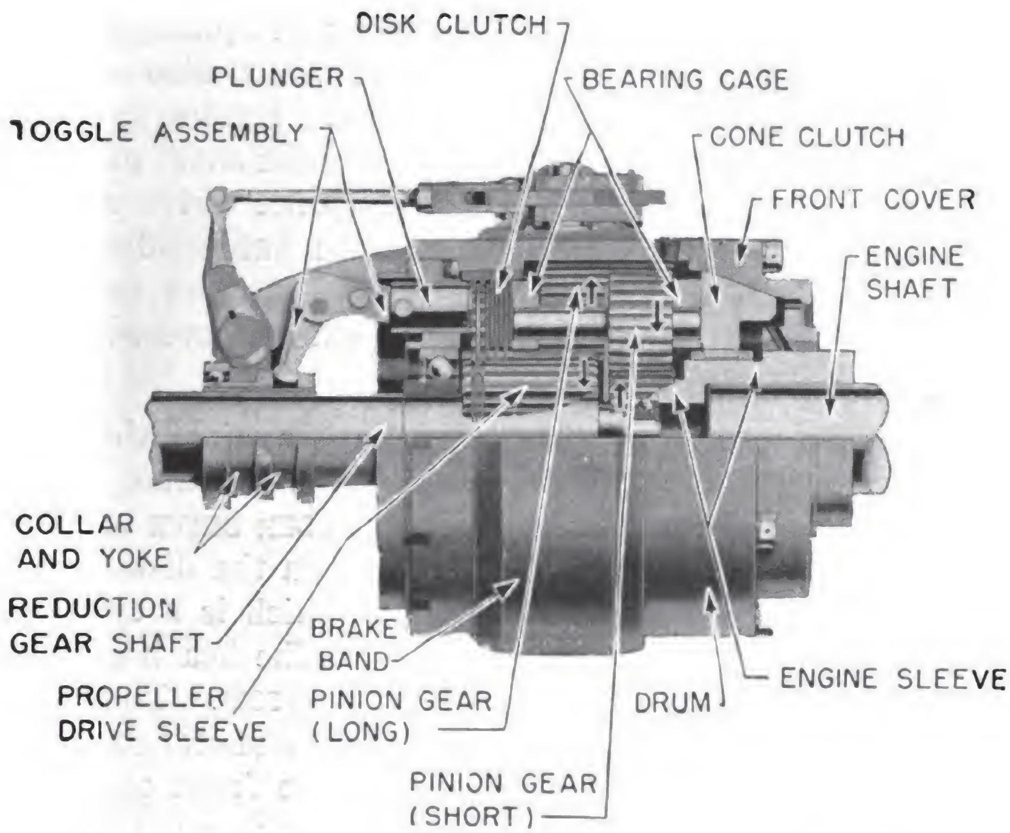


Figure 3–4.—Cutaway view of Joe's clutch and reverse gear.

lever and the COLLAR AND YOKE ASSEMBLY slides the collar lengthwise to the left along the REDUCTION GEAR SHAFT. This motion operates the TOGGLE ASSEMBLY which, in turn, drives the three plungers to the right, pressing them hard against the DISK CLUTCH.

REVERSE ROTATION.—When the operating lever is thrown into the reverse position, the plungers are withdrawn, and both clutches are disengaged. At the same time the brake band is tightened around the drum, holding the drum stationary. The bearing cage is locked to the drum. The cone clutch rotates freely out of contact with the front cover. Then the motion from the engine shaft to the reduction gear shaft is transmitted through the inner gear assembly.

The reverse gear pinions are held in the bearing cage, which is stationary for reverse rotation. There are three SHORT PINIONS, each in mesh with the small inner

gear of the engine sleeve. The three short pinions mesh with the three LONG PINIONS, each of which also meshes with the PROPELLER DRIVE SLEEVE GEAR. Engine rotation is transmitted from the engine sleeve to the short pinions, to the long pinions, and to the propeller drive sleeve. These pinions (gear train) cause the REDUCTION GEAR SHAFT to rotate opposite to the engine rotation (see arrows in fig. 3–4), and give the propeller a reverse rotation.

When the plungers are driven hard against the disk clutch, the disks are locked together by friction. This locks the DRUM HOUSING to the PROPELLER DRIVE SLEEVE. In addition, the force of the plungers on the disk clutch is transmitted to the BEARING CAGE, which is a cylinder containing the reverse gear pinions. The bearing cage, in turn, is pressed against the CONE CLUTCH. Thus, the cone clutch is forced against its seat in the FRONT COVER of the gear box, clamping the clutch to the front cover by friction. Since the cone clutch is in mesh on its inner surface with the engine sleeve, which is in turn keyed to the engine shaft, the front cover is now locked to the engine shaft. The front cover must rotate with the engine shaft, in the same direction.

Now, since the front cover is bolted to the drum housing, which is locked to the propeller drive sleeve by the disk clutch, there is a complete lock from the engine shaft to the reduction gear shaft. The entire assembly rotates as a unit in the same direction as the engine shaft; this motion gives the propeller a forward rotation.

Note that in figure 3–5, which shows the mechanism more clearly, the gears are set for reverse rotation, and the brake band is clamped to the drum. The parts which are shaded are held stationary by the brake band, and the remaining internal parts, which are not shaded, rotate. (The rotation of the engine shaft and engine sleeve is transmitted directly to the cone clutch and the short pinions. The cone clutch rotates freely out of contact with

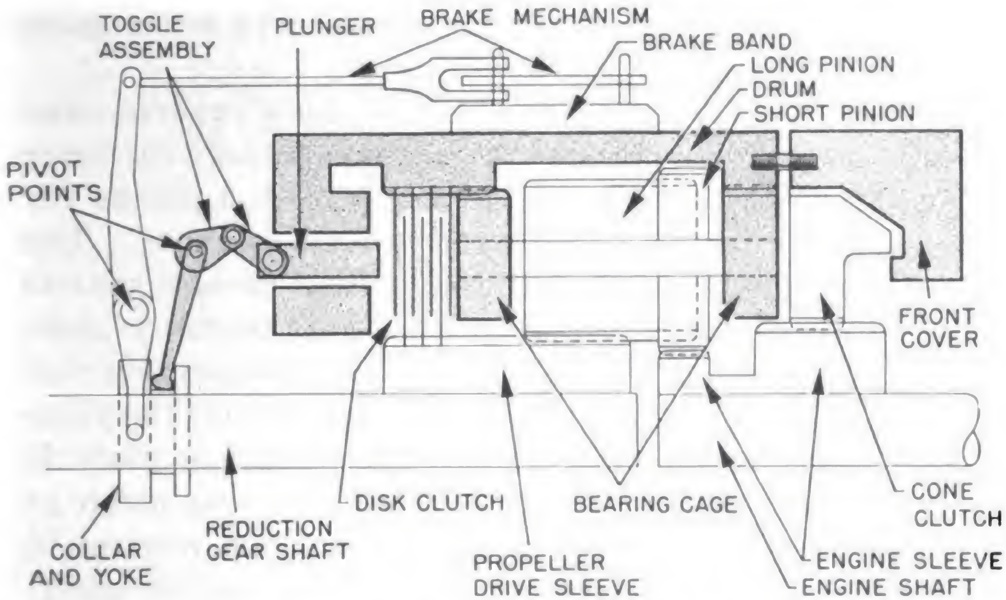


Figure 3–5.—Schematic diagram of Joe's reverse gear assembly.

the stationary front cover. The short pinions drive the long pinions, which drive the propeller drive sleeve. The latter unit is keyed to and drives the reduction gear shaft, which rotates opposite to the engine shaft.)

REDUCTION GEAR UNIT.—This unit is bolted to the reverse gear housing, as shown in figure 3–3. It consists merely of an EXTERNAL GEAR, mounted on the reduction gear shaft, and in mesh with a larger INTERNAL GEAR, mounted on the propeller shaft. Power is transferred, at a reduced speed, from the smaller drive gear to the larger internal gear.

LUBRICATION OF THE ASSEMBLY.—Lubrication of the clutch and reverse gear mechanism is accomplished by means of a drilled passage in the crankshaft which supplies oil, as a spray, to the gears and other moving parts. This oil returns to the engine sump by gravity.

Lubrication of the reduction gear unit is accomplished by an external line from the engine's main oil gallery. Oil is sprayed over the gears and moving parts to lubricate and cool them. Excess oil either drains back to the engine sump by gravity, or, where the unit is below the

engine, returns to the sump by means of a scavenging pump.

OPERATIONAL ADJUSTMENTS.—With Joe's reverse gear systems, adjustments can be made to compensate for wear of parts. These systems are provided with a means for increasing the pressure between clutch surfaces. The pressure plate in the disk clutch of a Joe's reverse gear is one example of an adjustable unit. This pressure plate is threaded into the gear case, and the pressure exerted on the clutch disks is dependent upon the amount the plate is screwed into the case. When the pressure plate is being adjusted, it should be tightened only one notch at a time. By working the shifting lever from neutral to the ahead position, the degree of tightness can be ascertained. (A normal shift should be made with ease.) If undue force is required to make the shift, the pressure plate is too tight and should be loosened one notch. The locking block and bolt must be replaced.

If the clutch requires adjustment at frequent intervals, the reverse gear should be disassembled and thoroughly inspected. Particular attention should be given to the clutch disks in order to ascertain that they are not excessively worn. (Clutch slippage in the astern position is caused by insufficient pressure on the brake band. Since the reverse clutch band is fibre lined and more subject to wear than the metallic disks used for the ahead drive, it requires more frequent adjustment.)

Since you will be required to make operational adjustments to clutches on small-boat engines, you should be familiar with the procedures for forward drive and reverse drive adjustments.

For FORWARD DRIVE, the clutch adjustment should be made with the gear in reverse, as shown in figure 3–6 which illustrates reverse gear adjustment and positions. The gears are generally adjusted at the factory so that each of the three plungers (18 of fig. 3–6), when in the forward position, exert uniform pressure against the clutch disks. Each toggle is numbered, and if the

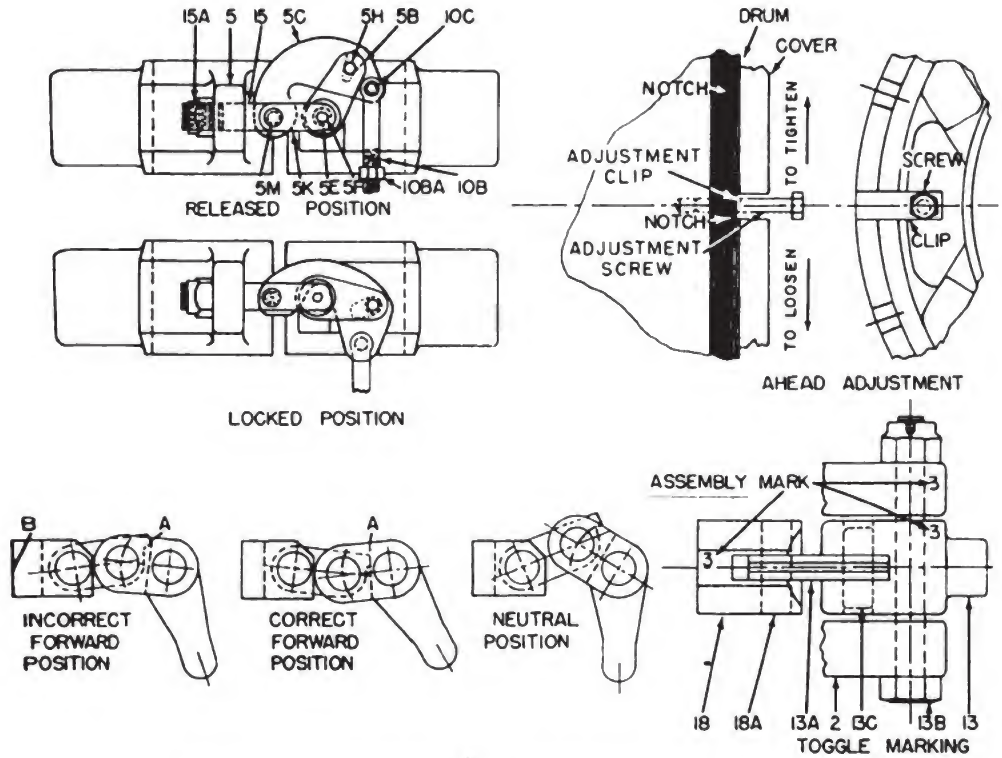


Figure 3–6.—Reverse gear adjustment and positions.

plungers are removed, they must be put back in the same position. When properly installed, the toggles pass center in the forward drive and shut tightly at A, as shown in figure 3–6. If all three plungers do not shut, they are liable to jump out of the engaged position and cause the clutch to slip.

When adjusting the gear for forward drive, loosen the adjusting screw and lift the clip out of its notch. This permits the cover to be turned to the right one or more notches, as required, to prevent the gear from slipping. The gears of the Models DB and DD power boat engines have an offset clip which, when reversed, afford a finer adjustment than a full notch. The gear must not be adjusted so that the lever cannot be given its full throw; this will result in excessive wear and overheating.

After the adjustment has been made, replace the adjusting screw and clip, as well as the cotter pins that were removed.

For REVERSE DRIVE ADJUSTMENT, pull the operating lever in the reverse position, and adjust nut 15A, figure 3–6. Tighten the nut sufficiently to prevent the drum from rotating under full engine power. DO NOT ADJUST TOO TIGHT SO THAT THE CAM (5C) CANNOT BE PULLED INTO LOCKED POSITION, as shown in figure 3–6.

If it becomes necessary to replace the toggles, you should replace the complete assembly, which includes the toggles (13), the links (13A), the toggle bolts (13B), and the plungers (18). After the gear has been assembled, it should be carefully examined to see that the correct closed position is obtained, as shown in figure 3–6.

If one of the links (13A) shows the correct closed position and two links show an open position, the closed link should be filed slightly until they all bear equally at this point, when closed. When the adjustment is fairly tight, the lever should throw in with a snap and require a sharp pull to disengage the toggles;. that is, the clutch should lock into position.

Friction Clutch Troubles

Difficulties which may necessitate maintenance or repair of these clutches will vary, depending upon the classification of the clutch (wet or dry, disk or band) and also upon the method of operation (hand, hydraulic, pneumatic, vacuum). The troubles discussed in this section —slippage and wear, freezing, and noise—are common to most friction-type clutches.

SLIPPAGE AND WEAR.—It would be difficult to consider these separately, since they can each be the cause of the other, and each intensifies the other's effect. Slippage generally occurs at high engine speed, when the engine is delivering the greatest torque; it results in lowered efficiency, loss of power, and rapid wear of the clutch friction surfaces.

There are several possible causes of clutch slippage: wear, insufficient pressure, overload, and fouling.

Over a period of operation, a normal amount of WEAR

results from extended engaging and disengaging of the surfaces, and if the surfaces are rough, this wear will be speeded up.

When a friction clutch is being overhauled, care must be taken not to damage the bearing surfaces; small nicks must be stoned, and if the scoring is serious, the damaged surface must be refinished, or the part replaced. Since water has a deteriorating effect on clutch facings, every effort must be made to keep dry-type clutches free of moisture.

Engaging the clutch while racing the engine may be another cause of EXCESSIVE WEAR; it also will strain the entire drive system.

Some types of friction clutches are not adjustable, but are dependent upon the initial compression in the pressure springs. Twin-disk clutches, such as those on the Gray Marine engines, are equipped with a spring pressure system. With this system, it is important to check the springs whenever the clutch is disassembled. This should be done with a spring tester. However, if none is available, a check on the free lengths of the springs will give an indication of their condition. The manufacturer's instructions should be consulted for the proper values.

When an engine is OVERLOADED, torque may be increased to such an extent that slippage will occur. Obviously, this trouble can be prevented by keeping the load within specified limits. Whenever an engine is fully loaded, watch for symptoms which indicate slippage.

A dry-type clutch may slip when the lining surfaces become FOULED with oil, grease, or water. Oil and grease usually reach the clutch surfaces because of careless maintenance procedures, such as using an excess of grease in lubricating or overfilling the gear case with oil. When oil in a gear case foams, there will be leakage from the shaft bearings. Foaming may be caused by air leaks in the oil suction line, or by overfilling. When foaming occurs, inspect all lube oil lines for air leaks, and check for proper oil level.

When a reduction gear case is being filled, add only sufficient oil to bring the level up to the FULL mark. Do not add or measure oil when the unit is in operation, because it is impossible to get an accurate oil reading.

In the case of a twin-disk clutch installation, leakage of oil from the rear main bearing of the engine may cause oil to appear on the clutch surfaces. This leakage may be caused by excessive bearing clearance, overfilling of the engine crankcase, plugged crankcase breather cap, or excessive piston blow-by. The crankcase breather cap must be cleaned periodically to prevent it from becoming clogged.

Another source of fouling is grease that may be deposited on a dry-type clutch while it is being overhauled. The parts should not be handled with greasy hands, and any grease that may be deposited should be removed with an approved cleaner. For the pneumatically operated friction clutches, where rubber parts are used, only a dry cloth should be used on clutch facings.

When clutch slippage becomes apparent, steps should be taken immediately to correct the trouble. If slippage occurs, the clutch surfaces are probably worn. If slippage has occurred, always check the thickness of a clutch lining. When a lining is worn excessively, it should be replaced; tightening the adjusting device will not compensate for the excessive surface wear. Instead, such adjustments may lead to the scoring of the mating clutch surfaces.

FROZEN CLUTCH.—When a clutch fails to disengage, it is said to be "frozen." Failure to disengage may be caused by a defective clutch mechanism, or by water in the clutch linings.

When a clutch becomes frozen, the operating mechanism should be inspected. Check the control rods for obstructions or loose connections, and check for excessive clearances in the throw-out bearing pressure plate, the pivots, and the toggles. In a twin-disk clutch, warped

disks will cause the clutch to freeze. (Warped disks are caused by extended running in neutral position.)

If a dry-type clutch is equipped with molded-type clutch linings, moisture will cause the linings to swell and to become soft. When this occurs, many linings tend to stick to the mating surfaces. Every effort should be made to prevent moisture from getting to the clutch linings. If a molded lining becomes wet, it should be permitted to dry in the disengaged position. Allowing the linings to dry in the engaged position increases the possibility of sticking.

CLUTCH NOISE.—Dry-type clutches may produce a chattering noise when the clutch is being engaged. Excessive clutch chatter may result in damage to the reverse and reduction gears, and may cause the clutch linings to break loose, resulting in complete clutch failure.

The principal cause of clutch chatter is fouling of the linings by oil, grease, or water. Every possible precaution should be taken against the entrance of oil, grease, or water into the unit.

When clutch chatter occurs as a result of fouling, replacement of the linings is the only satisfactory means of repair. All metal parts of the clutch must be cleaned in accordance with manufacturer's instructions.

AIRFLEX CLUTCH AND GEAR ASSEMBLY

On the larger Diesel-propelled ships, the clutch, reverse and reduction gear unit has to transmit an enormous amount of power. To maintain the weight and size of the mechanism as low as possible, special clutches have been designed for large Diesel installations. One of these is the AIRFLEX CLUTCH and gear assembly used with General Motors 12-567A engines on LST's.

A typical airflex clutch, reverse and reduction gear assembly, for AHEAD and ASTERN rotation, is shown in figure 3–7. There are two clutches, one for forward rotation and one for reverse rotation. The clutches are bolted to the engine flywheel by means of a steel SPACER, so that

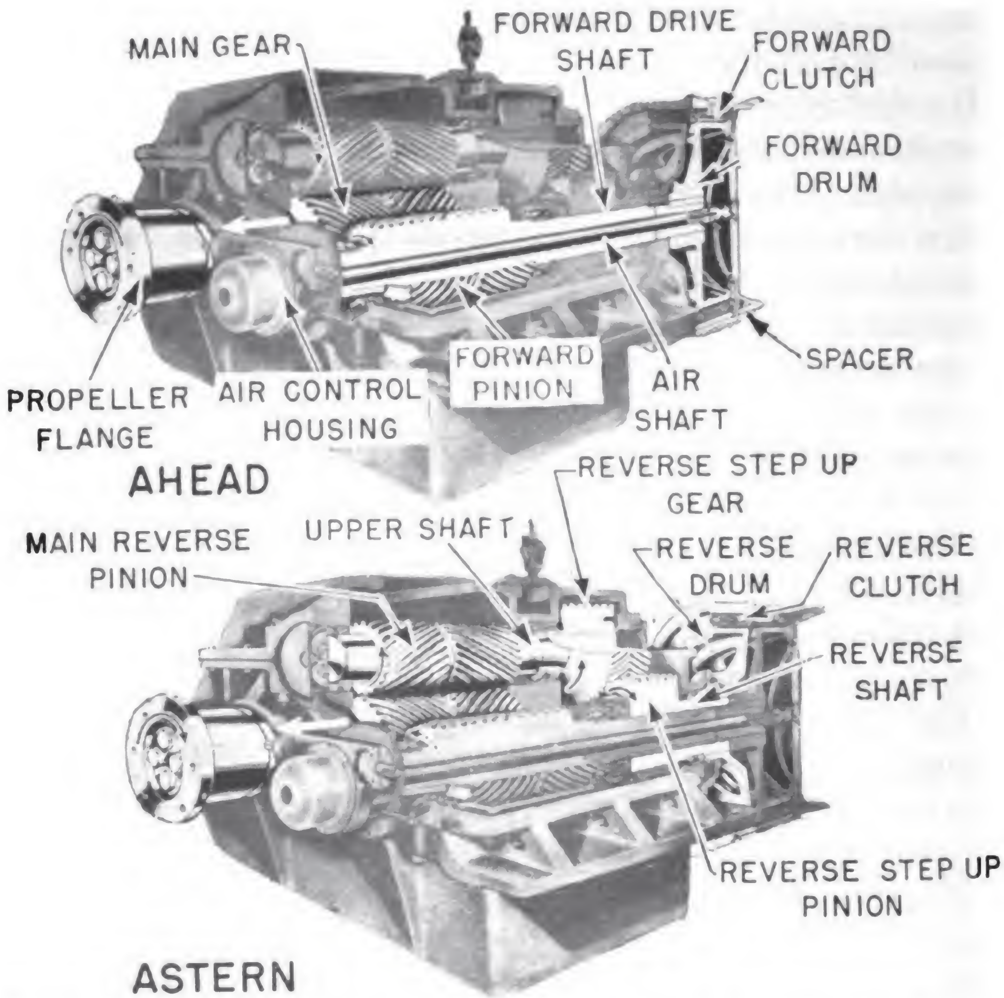


Figure 3–7.—Airflex clutch reverse and reduction gear assembly for General Motors 12-567A engine.

they both rotate with the engine at all times, and at engine speed. Each clutch has a flexible tire (or gland) on the inner side of a steel shell. Before the tires are inflated, they rotate out of contact with the drums, which are keyed to the forward and reverse drive shafts. When air under pressure (100 psi) is sent into one of the tires, the inside diameter of the clutch decreases. This causes the friction blocks on the inner tire surface to come in contact with the clutch drum, locking the drive shaft with the engine.

Forward Rotation

The parts of the airflex clutch which give the propeller ahead rotation are illustrated in the upper view of figure

3–7. The clutch tire nearest the engine (forward clutch) is inflated to contact and drive the FORWARD DRUM with the engine. The forward drum is keyed to the FORWARD DRIVE SHAFT, which carries the double helical FORWARD PINION at the after end of the gear box. The forward pinion is in constant mesh with the double helical MAIN GEAR, which is keyed on the propeller shaft. By following through the gear train, you can see that, for ahead motion, the propeller rotates in a direction opposite to the engine's rotation.

Reverse Rotation

The parts of the airflex clutch which give the propeller astern rotation are illustrated in the lower view of figure 3–7. The REVERSE CLUTCH is inflated to engage the REVERSE DRUM, which is then driven by the engine. The reverse drum is keyed to the short REVERSE SHAFT, which surrounds the forward drive shaft. A large REVERSE STEP-UP PINION transmits the motion to the large REVERSE STEP-UP GEAR on the UPPER SHAFT. The upper shaft rotation is opposite to the engine's rotation. The MAIN REVERSE PINION on the upper shaft is in constant mesh with the MAIN GEAR. By tracing through the gear train, you'll see that, for reverse rotation, the propeller rotates in the same direction as the engine.

The diameter of the main gear of the airflex clutch is approximately 2½ times as great as that of the forward and reverse pinions. Thus, there is a speed reduction of 2½ to 1 from either pinion to the propeller shaft.

Since the forward and main reverse pinions are in constant mesh with the main gear, the set that is not clutched in will rotate as idlers driven from the main gear. The idling gears rotate in a direction opposite to their rotation when carrying the load. For example, with the forward clutch engaged, the main reverse pinion rotates in a direction opposite to its rotation for astern motion (note the dotted arrow in the upper view of figure 3-7). Since the drums rotate in opposite directions, a special device, which

will be described later, is installed to prevent the engagement of both clutches simultaneously.

Airflex Clutch Control Mechanism

The airflex clutch is controlled by an operating lever which works the AIR CONTROL HOUSING, located at the after end of the forward pinion shaft. The control mechanism, shown with the airflex clutches in figure 3–8, directs the high pressure air into the proper paths to inflate the clutch glands (tires). The AIR SHAFT, which connects the control mechanism to the clutches, passes through the forward drive shaft.

The supply air enters the control housing through the AIR CHECK VALVE and must pass through the small AIR ORIFICE. The purpose of the restricted orifice is to delay the inflation of the clutch to be engaged, when shifting from one direction of rotation to the other. The delay is necessary to allow the other clutch to be fully deflated and out of contact with its drum before the inflating clutch can make contact with its drum.

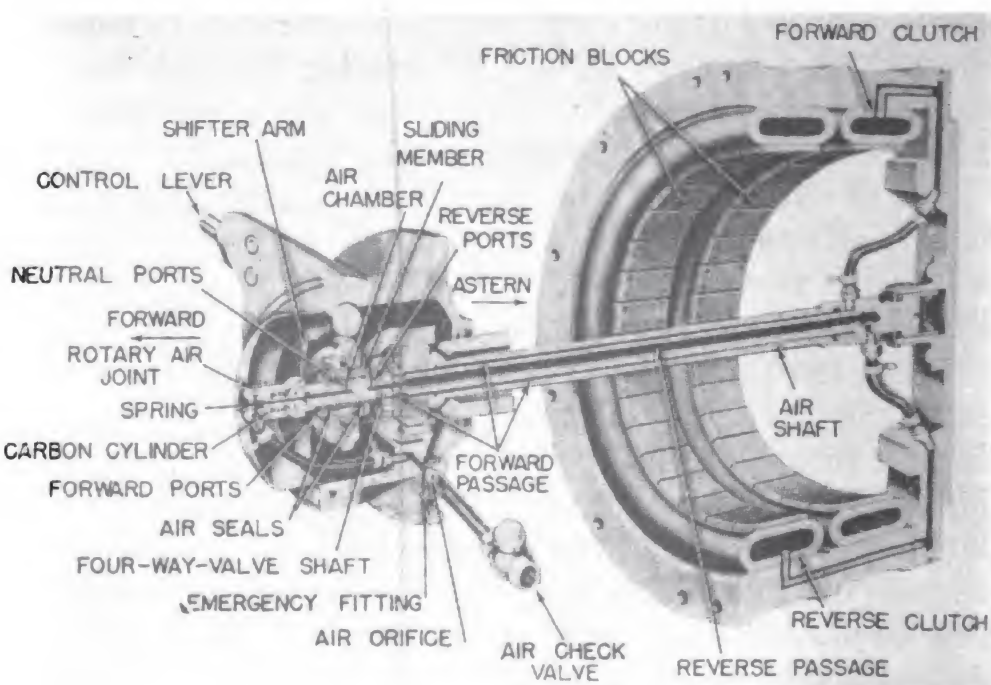


Figure 3–8.—Airflex clutches and control valves.

The supply air goes to the ROTARY AIR JOINT in which a hollow CARBON CYLINDER is held to the valve shaft by spring tension. This prevents leakage between the stationary carbon seal and the rotating air valve shaft. The air goes from the rotary joint to the FOUR-WAY AIR VALVE. The sliding-sleeve assembly of the four-way valve can be shifted endwise along the VALVE SHAFT by operating the CONTROL LEVER.

When the SHIFTER ARM on the control lever slides the valve assembly away from the engine, air is directed to the forward clutch. The four-way valve makes the connection between the air supply and the forward clutch, as follows: There are eight NEUTRAL PORTS which connect the central air supply passage in the valve shaft with the sealed AIR CHAMBER in the SLIDING MEMBER. In the neutral position of the four-way valve, as shown in figure 3–8, the air chamber is a dead end for the supply air. However, in the FORWARD position of the valve, the sliding member uncovers eight FORWARD PORTS, which connect with the FORWARD PASSAGES conducting the air to the forward clutch. The air now flows through the neutral ports, air chamber, forward ports, and forward passages to inflate the forward clutch gland. As long as the valve is in the forward position, the forward clutch will remain inflated and the entire forward air system will remain at a pressure of 100 psi.

At this point, let us assume that the bridge signals you to reverse the propeller. In that case, just pull the operating lever back to neutral position, and hold it there for two or three seconds. Then pull the lever to the reverse idling position and wait about seven seconds, after which the reverse clutch is fully engaged. Then you can increase the reverse speed to whatever the bridge has called for.

Why was it necessary to pause at neutral and at reverse idling positions, and what has happened in the air control and clutch mechanism? When you shift to neutral, the forward ports are uncovered, and the pressure

air from the forward clutch and passage vents to the atmosphere. Pausing for two or three seconds at neutral allows time for the forward clutch to deflate and become disengaged before you start inflating the reverse clutch.

When you shift to reverse idling, the air chamber comes over the set of eight REVERSE PORTS which open to the central reverse passage in the air shaft. The pressure air begins to inflate the reverse clutch immediately; however, it takes about seven seconds to inflate it fully. When the clutch is in the reverse idling position, wait until the reverse clutch is fully engaged before increasing the speed. This prevents damaging the clutch by slipping.

The inflating air must pass through the single air orifice in the supply line, and this causes a delay of about seven seconds to fully inflate a clutch. However, in deflating either clutch, the air is vented through eight ports approximately the same size as the air orifice, so that deflating either clutch requires one or two seconds. Because of this arrangement, it is impossible to have both clutches engaged at the same time.

Lubrication

On most large gear units, a separate lubrication system is used. The lubricating system for the General Motors 12–567A unit is shown in figure 3–9. The oil is picked up from the gear box by an electrically driven, gear-type lubricating oil pump and is sent through a strainer and cooler. After being cleaned and cooled, it returns to the gear box to cool and lubricate the gears. In twin installations, such as shown in figure 3–9, a separate pump is used for each unit and a standby is interconnected for emergency use.

Airflex Clutch Troubles

The most common troubles encountered with Falk airflex clutches used on LST's, and the reduction and reverse gears with which they are used, are discussed in the paragraphs which follow.

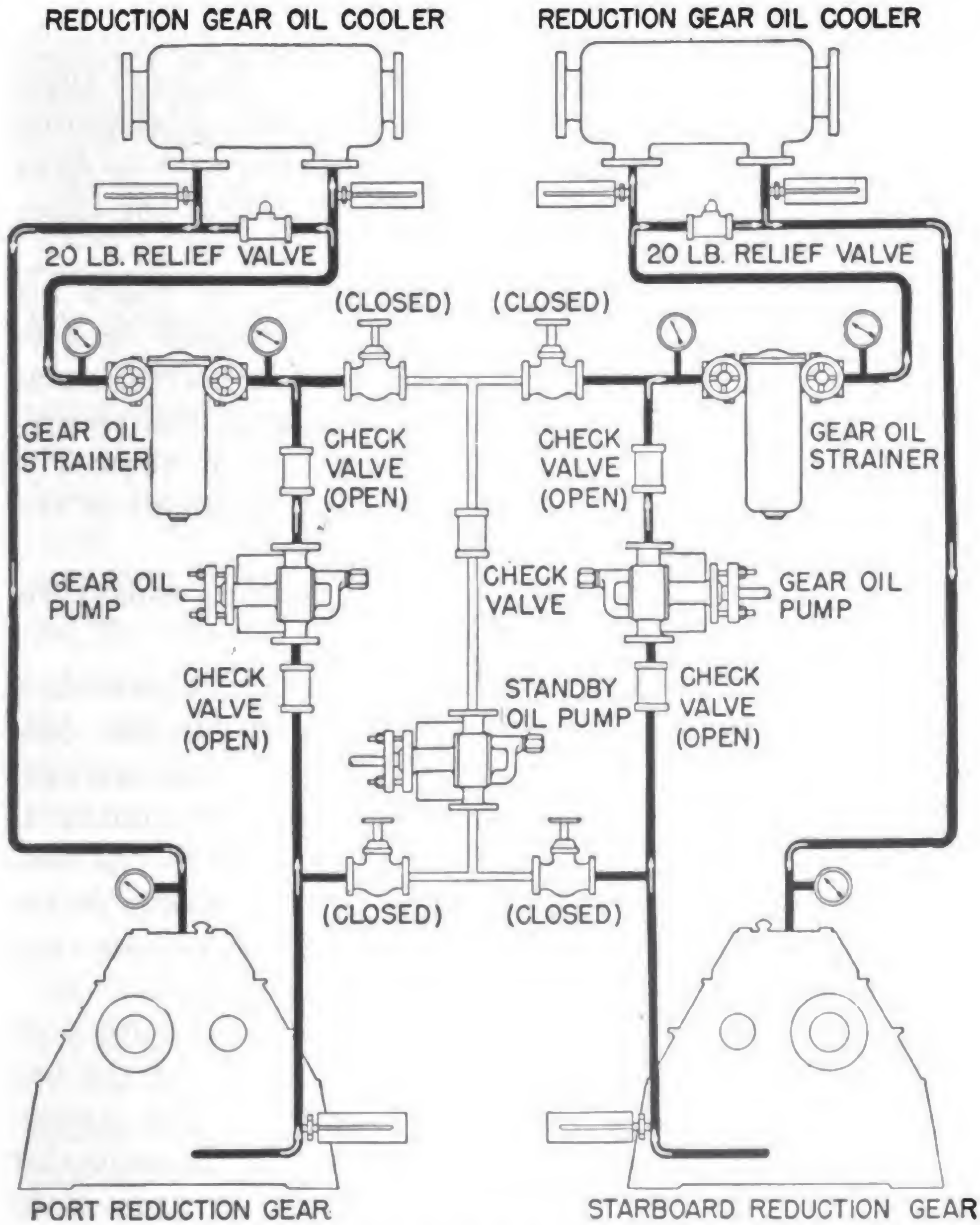


Figure 3–9.—Schematic diagram of reverse gear lubrication system (General Motors 12-567A engine).

BROKEN AIR SHAFT TUBE.—As mentioned earlier in the chapter, air is supplied to the clutches through a shaft mounted in the main pinion of the reduction gear. On some of the units, the air shaft consists of two tubes, one mounted inside the other.

Since the tubular-type air shaft, as originally manufactured, did not incorporate sufficient support for the inner

tube, failure is likely to occur as a result of vibration. Such failure is evidenced by a breakage of the inner tube, resulting in loss of air pressure in the clutch glands and disengagement of the clutch. Most of the tubular-type air shafts, however, have been modified so that the inner tube is stiffened against vibration.

WORN AIR SHAFT HEADER AND DRIVER.—A worn air shaft header and driver will cause the former unit to rattle when the engine is operating. In general, the cause of the wear is lack of lubrication. This wear can be prevented or minimized by lubricating the joint regularly. Excess wear, however, results from misalignment of the engine and the reduction gear.

When the header and driver are worn and noisy, the defective parts must be replaced.

RUPTURED BELLOWS IN CONTACT MAKER. A pressure-static contact maker, provided in the clutch air line, prevents operation of the clutches when the air pressure falls below the safe operating level. The contact maker is electrically connected in the interlock circuit of the control system. Therefore, when the contact maker is not functioning properly, the electrical control system will not operate and manual operation must be used.

Considerable trouble has been encountered with ruptured bellows in the contact maker. Rupture of the bellows is caused by vibration of the gears. The contact makers were originally mounted directly on the reduction gear case, and therefore subject to all the vibration of the gears. To prevent the occurrence of this trouble, a new rubber mount has been developed that isolates the vibrations of the gears and prevents damage to the bellows. If the bellows are ruptured within the pressure contact maker, the entire unit should be replaced.

CLOGGED AIR FILTER.—An air filter is provided in the inlet line to remove all water and foreign matter from the air before it enters the clutch glands. (The filter is built with a trap at the bottom to catch excess condensate. The trap is equipped with an opening at the bottom to

facilitate drainage of the condensate.) If the filter is not cleaned, clogging will result and cause air pressure to build up slowly in the clutches; this retards the operation of the mechanism.

To prevent clogging of an air filter, the case should be drained once each week. In addition, the air filter element should be removed and cleaned once each month. The element should be cleaned in an approved solvent.

A spare filter element is generally carried aboard a naval vessel so that it can be installed immediately after the clogged filter element has been removed. This reduces the amount of time that the clutch system is inoperative. The clogged filter should be cleaned before it dries out, then stored until needed for replacement the following month.

MISALIGNMENT OF REDUCTION GEARS.—Although the airflex clutch can absorb slight misalignment between the engine and the reduction gears, excessive misalignment will cause the load to be concentrated on the ends of the teeth, resulting in excessive pitting and gradual failure. Misalignment of reduction gears may result from *change in engine foundation, loose hold-down bolts,* and *permanent distortion of the ship.*

The most frequent cause of misalignment is the settling of the engine on its foundation, or the distortion of the foundation incident to beachings. To align the units properly requires a great deal of patience and care. The following procedure should be used to check the reduction gear shaft alignment with respect to the engine and the propeller shaft:

1. Place the reduction gear in its normal running position by lining up the faces of the clutch gland flange with the reverse drum. This can be accomplished by placing a straightedge across the full face of the gland flange, and checking the position of the clutch drum, with respect to the straightedge.

2. Clamp a dial indicator to the clutch gland flange so that parallel alignment may be checked on the outside of the reversing clutch drum, as shown in figure 3–10A.
3. Inflate the reversing clutch drum with air at 50 to 100 psi.
4. Starting with the indicator set at zero, rotate the entire clutch assembly 360°, taking readings at quarter points (90° apart). The readings must be within 0.015 inch in 180° of clutch rotation for parallel alignment (indicator reading on outside of drum). The gear shaft may be rotated by means of the engine jacking gear.
5. Clamp the dial indicator to the gland flange so that angular alignment may be checked on the after face of the drum (fig. 3–10A).
6. Starting with the indicator set at zero, rotate the entire clutch assembly 360°, taking readings at quarter points (90° apart). The readings must be within 0.025 inch in 180° of clutch rotation for angular alignment (indicator reading on face of drum).
7. Adjust the gear shims to obtain indicator readings outlined in steps (4) and (6). The maximum deflection at No. 6 engine crank of the engine, between any two quarters as determined by web gage readings, shall not exceed 0.003 inch.
8. With the coupling bolts removed, check the angular alignment of the gear and propeller shafts by inserting a feeler gage between the flange faces at quarter points (90° apart), as shown in figure 3–10B. The readings must be within 0.002 inch in 180° of shaft rotation for angular alignment. (Allowance must be made for the sag of the overhanging length of propeller shaft. Either support the propeller shaft or determine the amount of sag.)

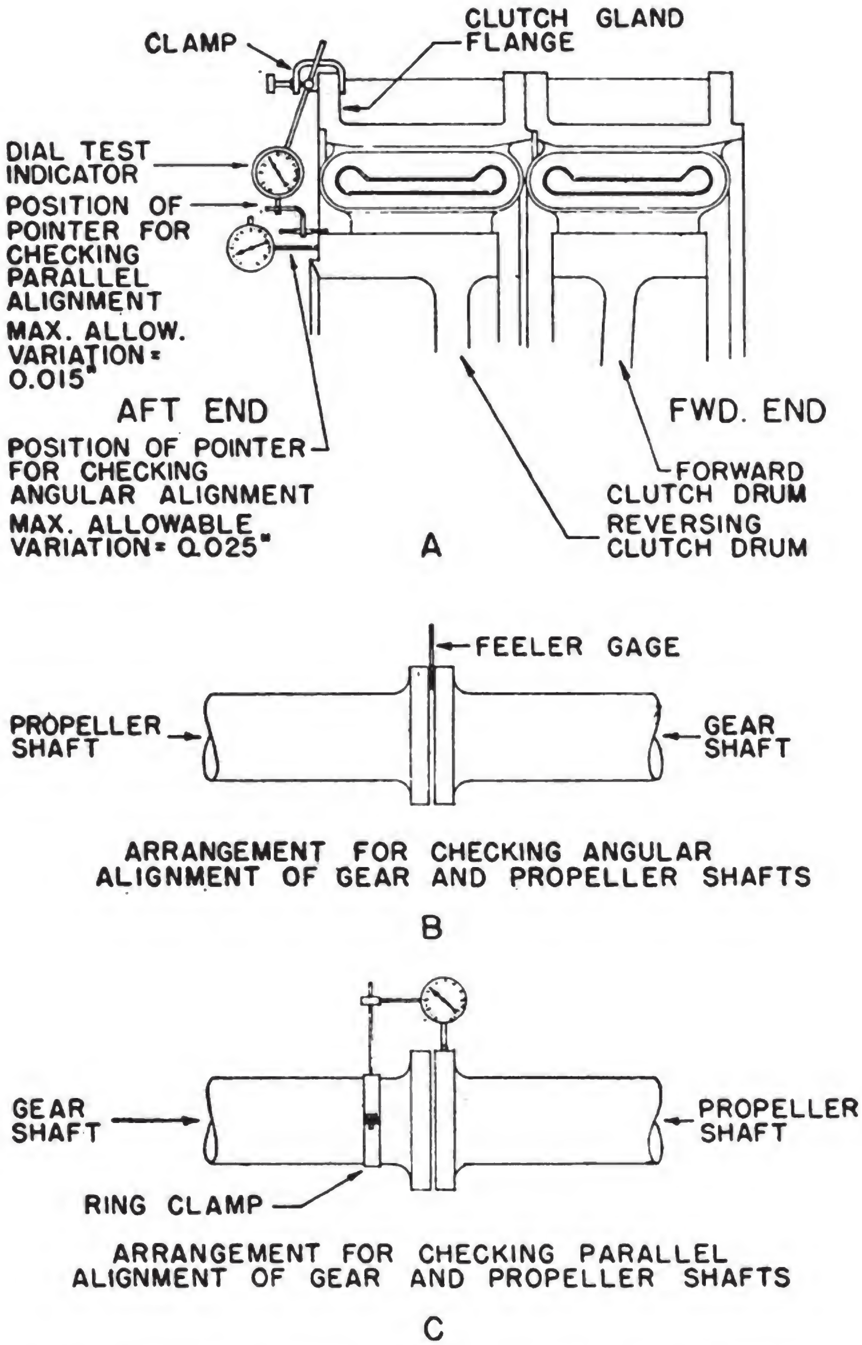


Figure 3–10.—Checking alignment of engine to gear, and alignment of gear shaft and propeller shaft.

9. Rotate the propeller shaft 180° and repeat checking clearances with the feeler gage, every 90°. These readings must also be within 0.002 inch in 180° of shaft rotation.

10. With the coupling bolts removed, clamp a dial indicator to the gear shaft to check for parallel alignment of the gear and propeller shafts (fig. 3–10C).
11. Starting with the indicator set at zero, rotate the gear shaft 360°, taking readings at quarter points (90° apart). The readings must be within 0.004 inch in 180° of shaft rotation for parallel alignment. The gear shaft may be rotated by the engine jacking gear.
12. Rotate the propeller shaft 180° and repeat step (11) above. These readings must also be within 0.004 inch and in 180° of shaft rotation.

Adjust the shims to obtain alignment readings outlined in steps (8) and (11). With LST vessels that have the engine and gear mounted on a common bedplate, the alignment of the gear and the propeller shafts should be adjusted by shimming of the bedplate. With PCE vessels, in which the engine and gear have separate foundations, the gear should first be aligned to the propeller shaft, then the engine aligned to the gear.

Misalignment of reduction gears can also result from *loose hold-down bolts.* If the hold-down bolts are not checked periodically for tightness, the unit will shift and become misaligned.

PERMANENT DISTORTION OF THE SHIP, generally caused by heavy seas or beachings, may result in misalignment of the engine and clutch, or of the propeller shaft and gear shaft. When distortion and misalignment are suspected, an alignment check should be made to avoid possible damage.

HYDRAULIC CLUTCHES OR COUPLINGS

The fluid drive, or fluid clutch is widely used on Navy installations. The use of the hydraulic couplings eliminates the need for a mechanical connection between the engine and the reduction gears. Hydraulic couplings function not only as a coupling, but also as a clutch.

Couplings of this type operate with a minimum of slippage.

Some slippage is necessary for operation of the hydraulic coupling, since it is upon the principle of relative motion between the two rotors that torque is transmitted. The power loss resulting from the small amount of slippage is transformed into heat which is absorbed by the oil in the system.

Advantages of Hydraulic Couplings

Compared with mechanical clutches, hydraulic clutches have a number of advantages. There is no mechanical connection between the driving and driven elements of the hydraulic coupling. Power is transmitted through the coupling very efficiently (97 percent) without transmitting torsional vibrations, or load shocks, from the engine to the reduction gears. This protects the engine, the gears, and the shafting from sudden shock loads which may occur as a result of piston seizure or fouling of the propeller. The power is transmitted entirely by the circulation of a driving fluid (oil) between radial passages in a pair of rotors. In addition, the assembly of the hydraulic coupling will absorb or allow for slight misalignment.

Hydraulic Coupling Assemblies

The two rotors and the oil-sealing cover of a typical hydraulic coupling are shown in figure 3–11. The PRIMARY ROTOR (IMPELLER) is attached to the engine crankshaft. The SECONDARY ROTOR (RUNNER) is attached to the reduction gear pinion shaft. The COVER is bolted to the secondary rotor and surrounds the primary rotor.

Before proceeding with the assembly of the rotors and the shafts in the coupling housing, study the structure of the rotors themselves. Each rotor is shaped like a half-doughnut with radial partitions. A shallow trough is welded into the partitions around the inner surface of the

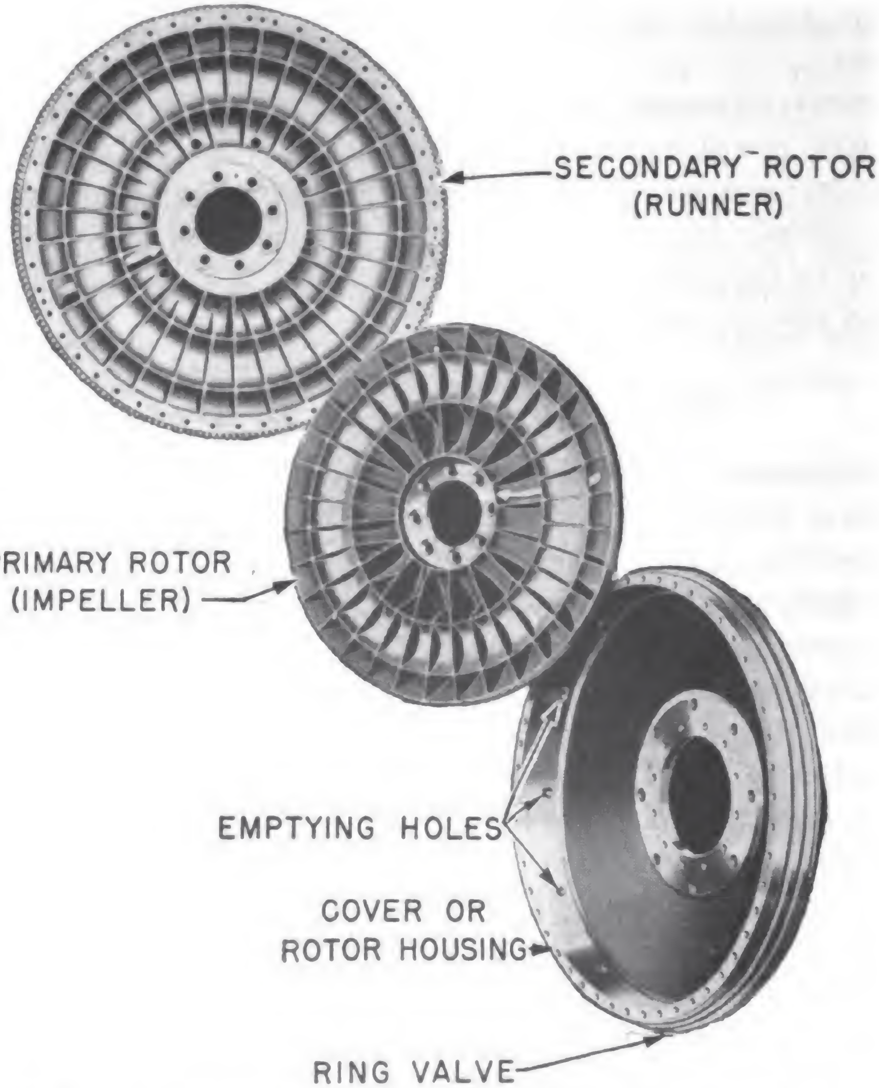


Figure 3–11.—Runner, impeller, and cover of hydraulic coupling.

rotor. The radial passages tunnel under this trough, as indicated by the white arrows in figure 3–11.

When the coupling is assembled, the two rotors are placed facing each other to complete the doughnut (fig. 3–12). The rotors don't quite touch each other, the clearance between them being $\frac{1}{4}$ to $\frac{5}{8}$ inch, depending on the size of the coupling. The curved radial passages of the two rotors are opposite each other, so that the outer passages combine to make a circular passage except for the small gaps between the rotors.

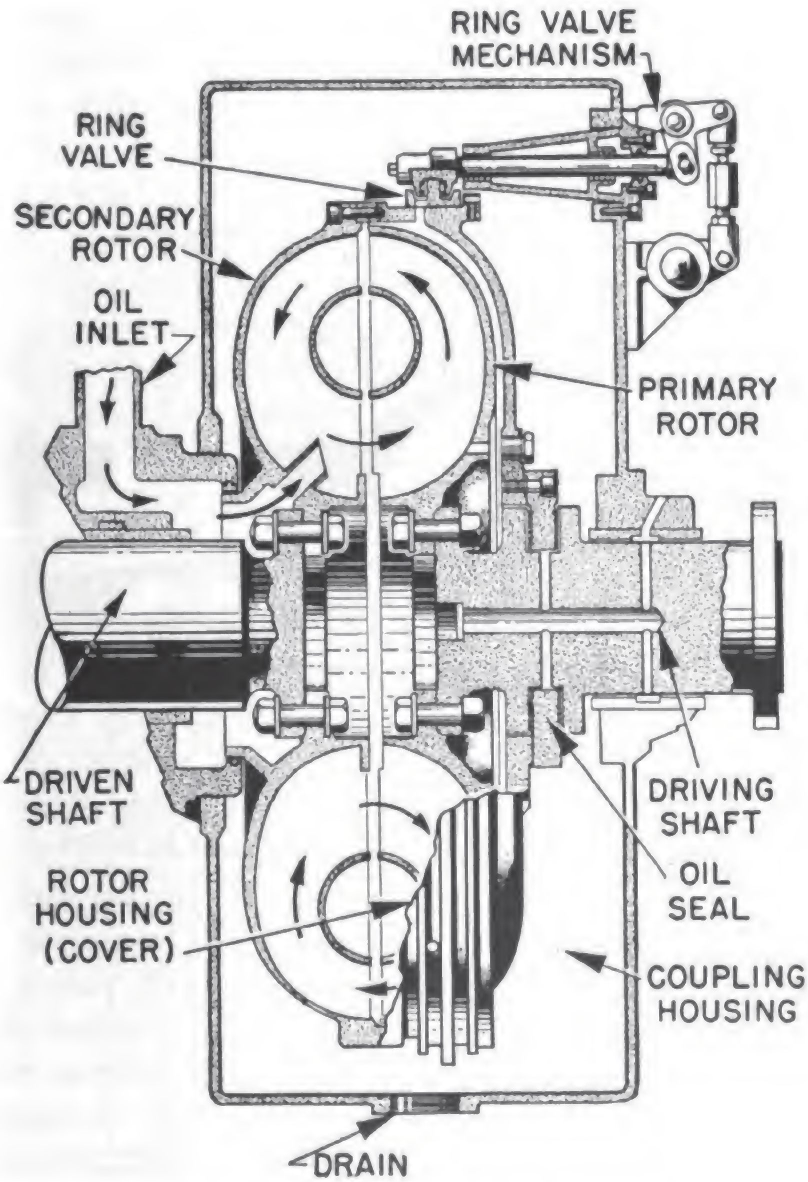


Figure 3–12.—Hydraulic coupling assembly.

In the hydraulic coupling assembly, shown in figure 3–12, the DRIVING SHAFT is secured to the engine crankshaft and the DRIVEN SHAFT goes to the reduction gear box. The OIL INLET admits oil directly to the rotor cavities, which become completely filled. The ROTOR HOUSING is bolted to the secondary rotor and has an oil-sealed joint with the driving shaft. A RING VALVE, going entirely around the rotor housing, can be operated by the RING VALVE MECHANISM to open or close a series of EMPTYING

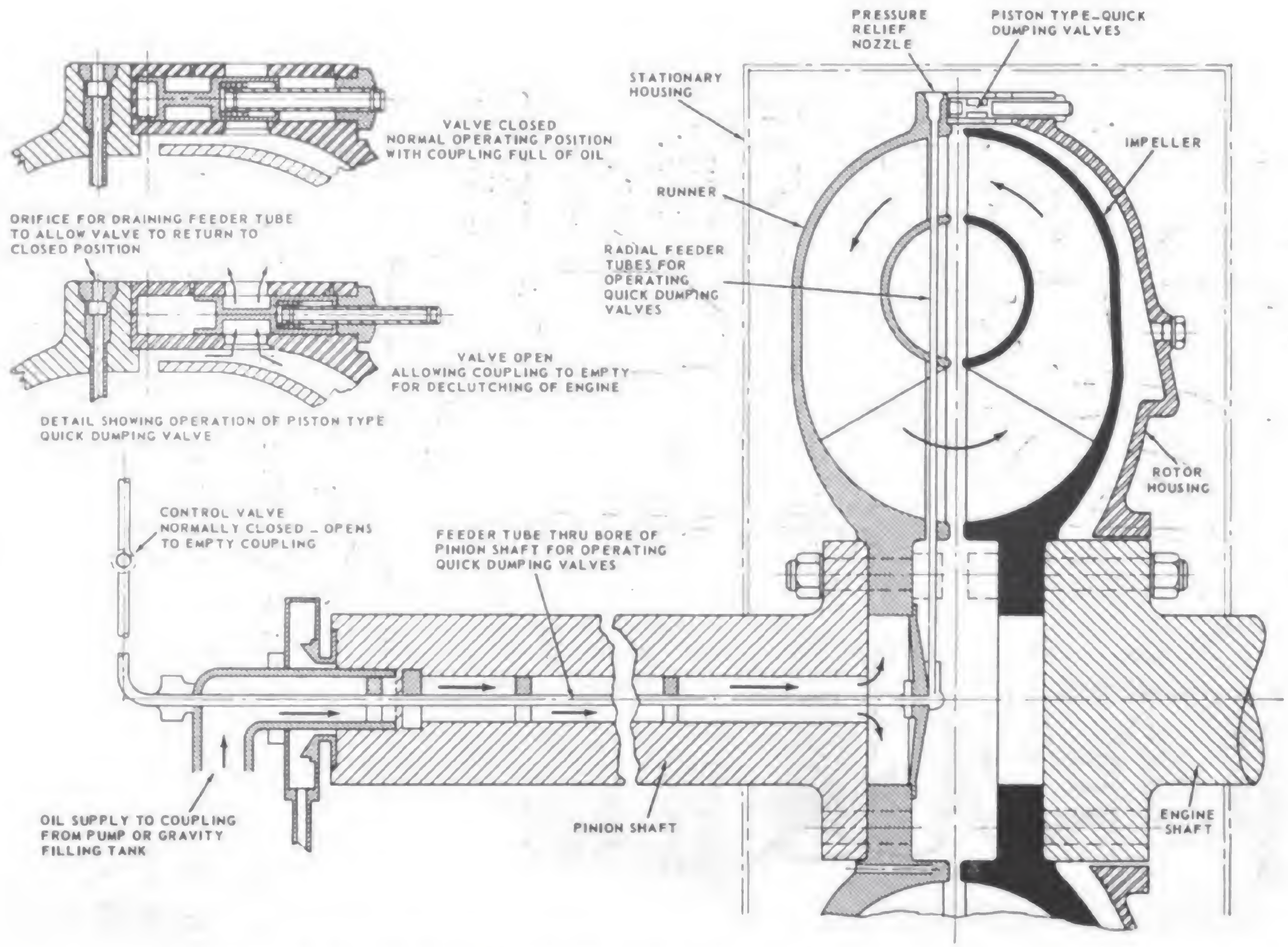


Figure 3-13.—Hydraulic-coupling with piston-type quick-dumping valve.

HOLES (fig. 3–12) in the rotor housing. When the ring valve is opened, the oil will fly out from the rotor housing into the coupling housing, draining the coupling completely in two or three seconds. Even when the ring valve is closed, some oil leaks out into the coupling housing, and additional oil enters through the inlet. From the coupling housing, the oil is drawn by a pump to a cooler, then sent back to the coupling.

Another coupling assembly used on several Navy ships is the quick-dump piston type hydraulic coupling, shown in figure 3–13. In this coupling, in which the operation is similar to the one described above, a series of piston valves, around the periphery of the rotor housing, are normally held in the closed position by springs. By means of air or oil pressure admitted to the valves, as shown in figure 3–13, the pistons are moved axially so as to uncover drain ports, allowing the coupling to empty. Where extremely rapid declutching is not required, the piston-valve coupling offers the advantages of greater simplicity and lower cost than the ring-valve coupling.

Another type of self-contained unit for certain Diesel-engine drives is the scoop control coupling, shown in figure 3–14. This coupling consists of an impeller to which is bolted an inner casing enclosing the runner, and an outer casing which acts as a reservoir, and has sufficient capacity to receive the contents of the working circuit. Calibrated nozzles in the inner casing allow a continuous flow of oil from the coupling circuit into the reservoir. The oil is picked up by a scoop tube mounted on the external manifold. The scoop tube is connected to an external handle which can be moved through an arc of about 70°. With the scoop in its fully extended position, the coupling circuit is full of oil and minimum slip is obtained. However, when the scoop is in its retracted position, all of the oil is in the reservoir and the coupling is completely disconnected. Thus, the coupling can serve as a disconnecting clutch. In addition, if variable output speed is desired, it can be obtained by placing the scoop

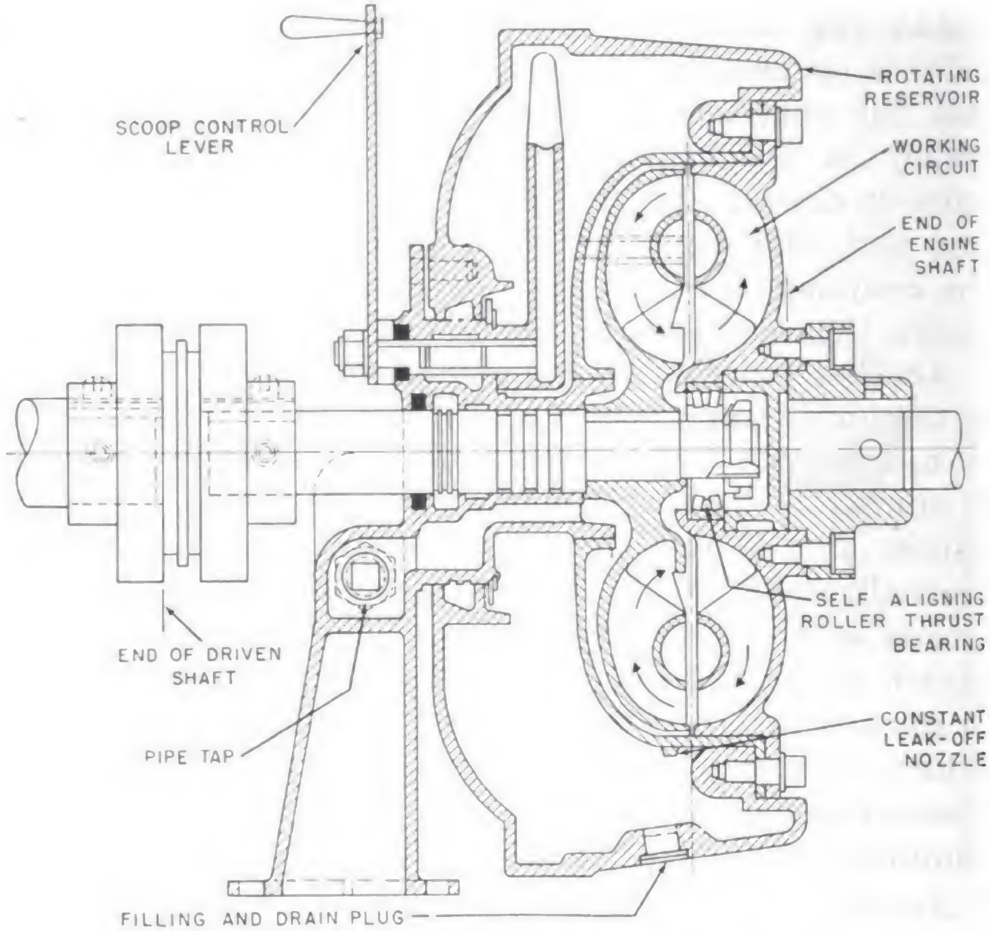


Figure 3–14.—Scoop control hydraulic coupling.

control lever in the intermediate position. The oil handled by the scoop tube can be circulated through an oil cooler where extra cooling is required.

When the coupling is stationary, the oil rests in the lower half below the level of the shaft and, consequently, no oil seal or gland is required. Thrust is provided for by means of a self-aligning roller bearing located in the propeller hub, and no external thrust bearings are needed.

Principles of Operation

Now we can see what happens in the coupling when the engine is started and the coupling filled with oil. The primary rotor turns with the engine crankshaft. As the primary rotor turns, the oil in its radial passages flows outward, under centrifugal force (see arrows in fig.

3–12). This forces oil across the gap at the outer edge of the rotor and into the radial passages of the secondary rotor, where the oil flows inward. The oil in the primary rotor is not only flowing outward, but is also rotating. As the oil flows over and into the secondary rotor, it strikes the radial blades in the rotor.

The secondary rotor soon begins to rotate and pick up speed, but it will always rotate more slowly than the primary rotor because of drag on the secondary shaft. Therefore, the centrifugal force of oil in the primary rotor will always be greater than in the secondary rotor. This causes a constant flow from primary to secondary at the outer ends of the radial passages, and from secondary to primary at the inner ends.

The power loss in the hydraulic clutch is small (3 percent) and taken up by friction in the fluid itself. This means that approximately 97 percent of the power delivered to the primary rotor is transmitted to the reduction gear. The lost power is transformed into heat, which is the reason for sending part of the oil through a cooler at all times.

Maintenance of Hydraulic Couplings

As long as the oil is circulated and cooled, the hydraulic coupling requires very little maintenance. The important points of maintenance are concerned largely with keeping the system clean. Since the reduction gear lubricating oil and the hydraulic coupling oil are generally in one system, the discussion which follows is applicable to both gears and couplings.

Troubles which may be encountered with a quick-dump type hydraulic coupling are: *dumping while under load, or excessive slippage.* These troubles are generally caused by the plugging of the pressure relief nozzles located in the periphery of the secondary rotors (fig. 3–13). These nozzles consist of drilled Allen setscrews, mounted in the secondary rotor at the ends of the radial tubes that feed air or oil to the dumping valves. The

nozzles permit the feeder tubes to drain when the air or oil supply valve is closed, thus allowing the dumping valve to return to the closed position. The nozzles also permit the draining of any oil that has leaked past the control valve when shut.

Leak-off nozzles are also provided in the periphery of the second rotor at the base of the dumping valves. The leak-off nozzles serve as flushing exits for the valves, and allow a continual flow of oil past the inlet port of the dumping valves. This washes away any particles of foreign matter that may have a tendency to collect as a result of the centrifugal action of the coupling.

The best way to prevent a hydraulic coupling from dumping while under load is to keep the oil system free from all foreign matter. Gasket compound and shredded copper from oil tube packings often cause trouble. Regardless of the source of foreign material, every possible precaution must be taken to keep the oil system clean. To aid in this, the system is equipped with a strainer which effectively catches, or traps, most of the foreign material. However, a small amount of foreign matter may reach the nozzles, therefore all nozzles must be blown out during each overhaul.

If nozzles become clogged during operation, it is possible to clear the nozzles by operating the dumping control several times. This action may blow the obstruction through the nozzle opening. If this method fails, it will be necessary to secure the engine, and remove and clean the nozzles.

ELECTROMAGNETIC CLUTCHES

Some Navy marine installations are equipped with electromagnetic slip clutches, often referred to as either electric or magnetic clutches. It is called a slip clutch because there is always some slipping between the driving and driven members. The speed of the driven shaft is slightly lower than that of the driving shaft.

The electromagnetic clutch, or coupling, shown in fig-

ure 3–15, consists of two separate rotating members. The inner member (secondary rotor or armature) is mounted on the driven shaft, and the outer member (field) is mounted on the engine crankshaft. An air gap of ample size separates the two parts of the coupling which fit together concentrically. The exciting direct current is introduced to the field through collector rings and brushes. This sets up a magnetic flux which holds the inner member and, with it, the driven shaft in a practically constant position to the primary rotor.

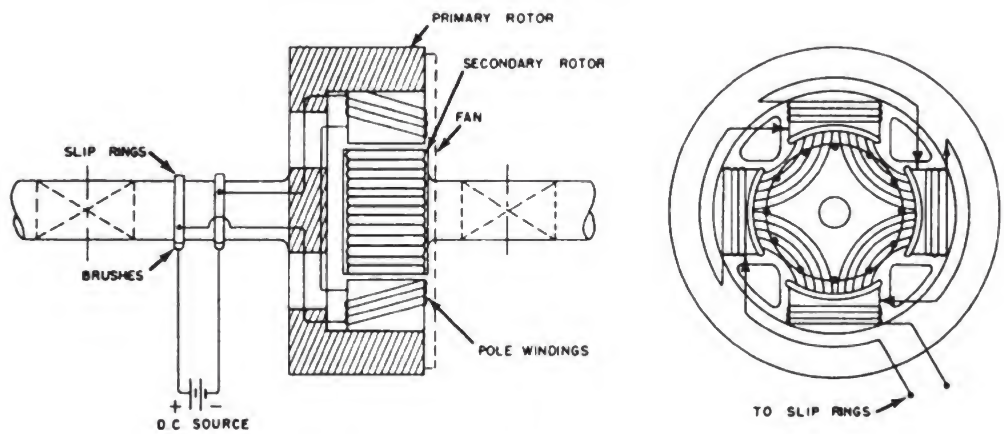


Figure 3–15.—Components of an electromagnetic clutch.

The direct-current coils, excited through slip rings installed on the shaft, are generally connected in series so that the same amount of current flows through all the coils. The coupling thus acts like an induction motor whose field, as well as armature, rotates.

Although the electromagnetic clutch operates on the principle of the induction motor, it is neither a motor or a generator. A motor converts electrical energy input to mechanical energy output, and a generator does the opposite. An electromagnetic clutch, however, merely transmits power from one shaft to another with no conversion in the type of energy employed.

Except for a slight decrease in speed with an increase in load, the induction motor is a constant-speed unit. The magnetic coupling, however, can be converted to a

variable speed unit by varying the amount of excitation current. This excitation is from direct current, while in the induction motor the excitation current is alternating. The outer member of the coupling carries the primary currents while the induced currents flow in the inner member. In order to obtain required motor action for the operation of the coupling, the two members cannot rotate at the same speed. This difference in speed is the slip of the clutch, and the load transmitted by the clutch varies with the difference in speed of the two members. Since small variations in load tend to cause the electric coupling to operate with a slightly different slip, the coupling acts as a damping device and reduces any severe oscillations between the two members of the clutch. To engage or disengage the clutch, it is only necessary to throw in, or pull out, an electric switch in the excitation current circuit.

The advantages of an electromagnetic clutch are similar to those mentioned previously for the hydraulic clutch. In addition, by adjusting the strength of the exciting current, very fine speed control of the driven shaft may be obtained and the propeller shaft may be operated at very low speeds, as in maneuvering.

Since the care and maintenance of electromagnetic clutches is generally the responsibility of an EM, this factor will not be discussed in this chapter. However, detailed information may be obtained from the manufacturer's instruction book for the specific installation.

DOG CLUTCHES

Dog type clutches perform much the same function as the friction type in that they allow the engine shaft to be disconnected from the propeller shaft. The dog clutch ensures a positive drive without slippage, and with a minimum amount of wear. (Forward drive is generally accomplished by one set of dogs, shown in figure 3–16, connected to the crankshaft, engaging and turning another set of dogs, connected to the propeller shaft.)

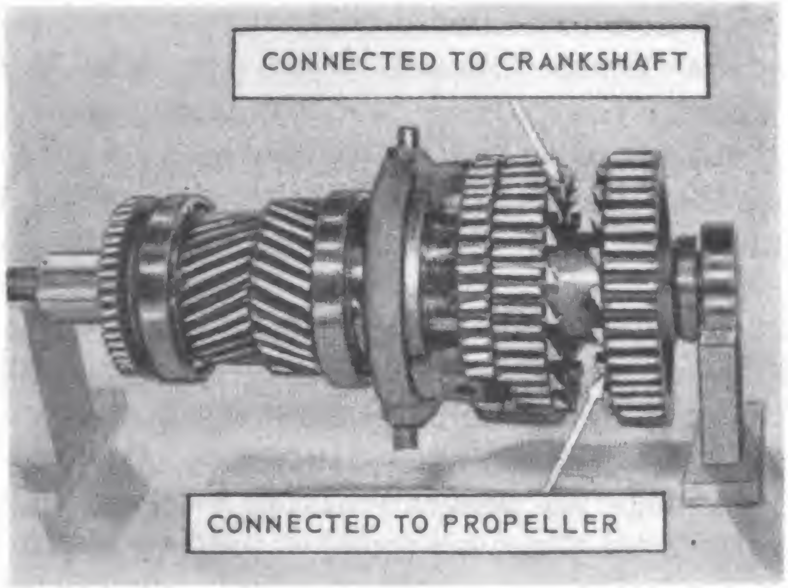


Figure 3-16.—Dog clutches.

In several installations, the dog clutch is used in addition to a friction clutch. In such cases, the dog clutch is engaged after the friction, or synchronizing, clutch brings the two shafts to an equal speed. The engagement of the dog clutch eliminates slippage, and holds friction clutch wear to a minimum. (The friction clutch, which consists of a cone and two friction rings, is illustrated in figure 3-17.)

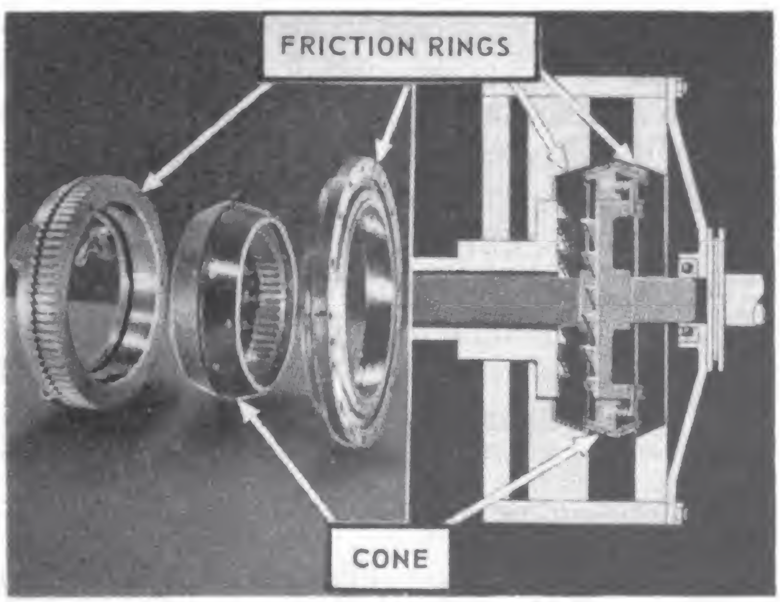


Figure 3-17.—The synchronizing clutch.

Any difficulty encountered in engaging the dog clutch will probably be due to burrs on the dogs or to misalignment of the mating parts. The dogs may become burred through normal usage. Repair should be made by disassembling the clutch and dressing down the burrs with a small hand grinder. When the damage is extensive and the burrs cannot be satisfactorily removed by grinding, the parts must be replaced. If difficulty in engaging a dog clutch is intermittent, misalignment is probably the cause. When this condition exists, try disengaging the clutch fully and then engaging it again. It may be that the mating dogs are prevented from shifting their relative positions by the synchronizers used to aid in bringing the two shafts to equal speed. Releasing the pressure on the engaging mechanism will usually permit relative motion between the mating dogs.

REDUCTION GEARS

There are many types of reduction and reverse gears in use by the Navy, all employing a series of gears meshing together and transmitting the engine torque to the propeller shaft. In many cases, reverse gears also perform the function of reduction gears in addition to providing a means for reversing the direction of rotation of the propeller shaft.

In order to understand the care and operation of mechanical reduction gears, the EN 2 should be familiar with the general principles of the design of gears. The manufacturers of the different gears in use in the service issue instruction pamphlets, which should be consulted.

This section deals primarily with the care of reduction gears. The information given here is applicable in general to all types of gears.

Lubrication of Reduction Gears

The efficient lubrication of all gears is of the utmost importance. Oil at the designated working pressure and

temperature must be supplied to the gears at all times while they are operating, either with or without load.

Lubricating oil is supplied to the gears from the main lubricating system, with a connection to each bearing and with nozzles so located that a constant stream of oil is supplied to the gears. (The stream of oil not only lubricates but also cools the gears.)

The military symbol lubricating oil used will vary, depending upon the type of propulsion plant. Diesel engines and main reduction gears require military symbol oil 9170, 9250, or 9370; whereas the oil used for most gasoline engines and their related gear units is of the 9000 or 3000 series, corresponding to the SAE number recommended by the equipment manufacturer for a given operating condition. An exception is the Packard marine engine, for which military symbol oil 1100 or 1120 is used.

Effects of Grit and Metal Particles

Oil must be free from all impurities, such as water, grit, and metal particles. Care must be taken to remove metal flakes and fine chippings as new gears are being worn into a working fit. Lint or dirt, if allowed to remain in the system will clog the oil-spray nozzles that lubricate the gears. Keep oil-spray nozzles open at all times. Never alter the oil-spray apparatus without proper authority.

Although the lube oil strainer performs its function satisfactorily, it may allow very fine particles to pass through the mesh, and the magnet may fail to pick up all metal particles. Fine particles of metal and dirt may become embedded in the babbitt of bearings, causing scratches and wear on the journals. Any fine abrasive that passes through the gear mesh will act as a lapping compound, removing metal from the reduction gear teeth.

Effects of Acid and Water in Oil

Water in the oil creates an extremely dangerous condition. Even small amounts of water will soon cause pitting

and corrosion of the gear teeth. Acid can be an even more serious problem. The oil must be tested frequently for water, as well as for acid content.

Too much emphasis cannot be placed on the importance of taking immediate corrective measures when salt water is found in the reduction gear lubricating oil system. Occasionally, gross contamination of the oil by salt water occurs when a cooler leaks or when leaks develop in a sump which is integral with the skin of the ship. The immediate location and sealing of the leak or removal of the source is not enough. Steps must also be taken to remove the contaminated oil from all steel parts and surfaces. Several instances are known where, because such treatment was postponed—sometimes for a week or less—gears, journals, and couplings became so badly corroded and pitted that it was necessary for naval shipyard forces to remove the gears and recondition the teeth and journals. Burned-out bearings also may result from salt-water contamination of the lubricating oil.

Water, generally due to condensation, is always present in small amounts. Air which enters the units contains moisture, which condenses when it strikes a cooler object and subsequently mixes with the oil. The water displaces oil from the metal surfaces and causes rusting. Water also reduces the lubricating value of the oil. Lubricating oil must be maintained in good condition by the proper use of the purifier and settling tanks. (Only large vessels have purifiers. Most boat applications have no means for changing oil; the practice is to dump and recharge.)

When the main engines are secured, the oil should be circulated until the temperature of the oil and of the reduction gear casing approximates the ultimate engine-room temperature that will be attained. While the oil is circulated, the cooler should be operated and the engine should be jacked continuously. The purifier should also be operated while the oil is being circulated, and after circulation until water is no longer discharged from the

purifier. This procedure eliminates condensation from the interior of the main reduction gear casing.

With continuous use, the lube oil will increase in acidity, and the free fatty acid will form a mineral soap which reacts with the oil to form an emulsion. Once the oil has emulsified, removal of water and other impurities becomes increasingly difficult. Even more important, however, is the fact that as the oil emulsifies it loses its lubricating quality. The formation of a proper oil film is rendered impossible, and it will be necessary to renovate the oil.

LEVEL OF OIL IN THE SUMP.—It is of extreme importance that the quantity of oil in the sump be maintained within the prescribed maximum and minimum levels. Too much oil as well as an insufficient supply in the sump can lead to trouble. If the oil level is above the prescribed maximum and the bull gear runs in the oil, the oil foams and heats as a result of the "churning" action.

In those gear installations where the sump tank extends up around the bull gear, and the normal oil level is above the bottom of the gear, an oil-excluding pan (sheet metal shield) is fitted under the lowest part of the gear to prevent its running in the sump oil. Under normal conditions, particularly on larger ship units, the bull gear comes in contact with only a small quantity of oil. The oil which tends to fill the pan is swept out by the gear and is drained back to the sump.

When there is too much oil in the sump, the gear will churn and aerate the oil, causing a sudden increase in its temperature. If this occurs, the engines must be slowed or stopped until the excess oil can be removed and normal conditions restored. Routine checks should be made to see that the lubricating oil is maintained at the proper level. Any sudden loss or gain in the amount of oil should be immediately investigated.

ABNORMAL SOUNDS.—Any unusual noises from reduction gears should be investigated immediately. In mak-

ing an investigation, a great deal will depend upon how an operator interprets the sound or noise heard.

The readings of lube oil pressures and temperatures may or may not be of any assistance in determining the reason(s) for abnormal sounds. A burned-out pinion bearing, or a burned-out main thrust bearing, can be detected by a rapid rise in oil temperature for the individual bearing. A certain sound or noise may indicate misalignment or improper meshing of the gear teeth. An inspection should be made to determine the cause of the abnormal sound or noise. The trouble should be remedied before the reduction gear is placed back in operation.

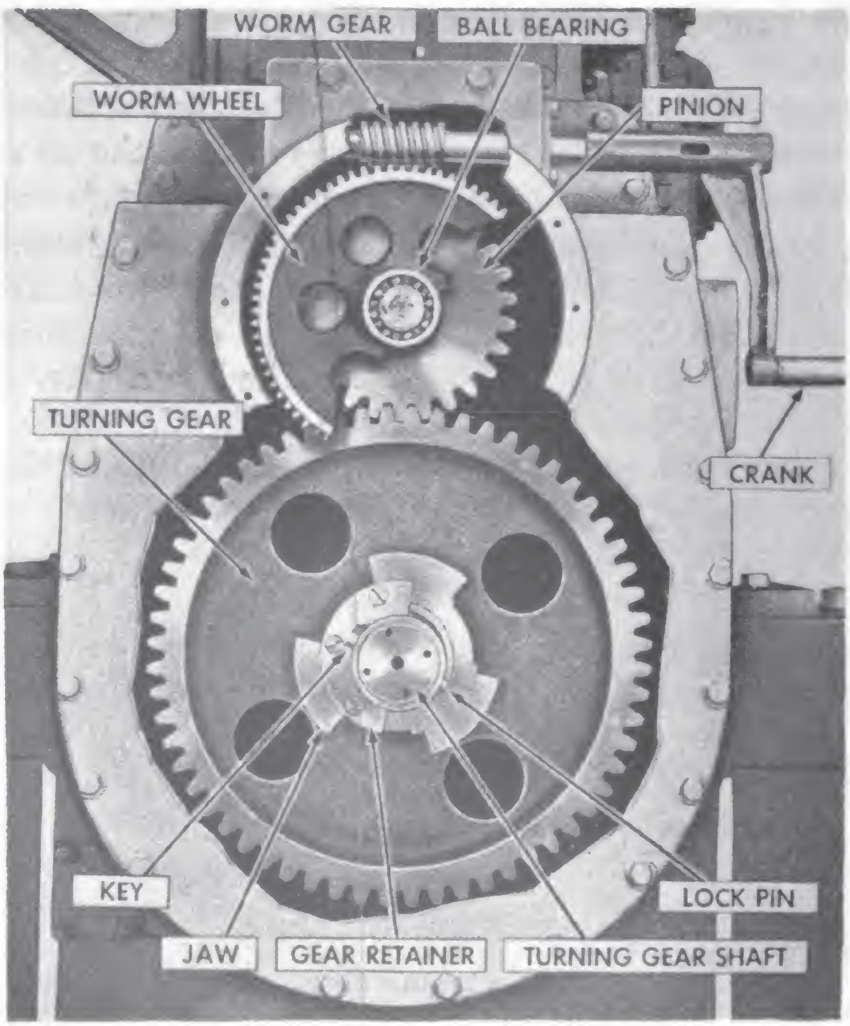


Figure 3–18.—Crankshaft turning gear assembly.

JACKING GEARS

Diesel main drive installations are equipped with a means of jacking, or turning over, an engine or reduction gears. A great majority of Diesel engines are jacked over by hand, particularly the smaller high-speed engines that drive the generators.

For instance, the Cooper-Bessemer Model GSB-8 reversible engine is provided with a turning gear at the forward end of the engine. This turning gear, manually operated by means of a removable handcrank (fig. 3–18), can be used to jack the engine in either direction. (When it is necessary to rotate the crankshaft only a few degrees, it is recommended that the operator use a bar inserted in one of the holes provided in the rim of the flywheel.)

The turning gear of the Cooper-Bessemer GSB–8 engine is engaged by means of a three-jaw coupling which slides axially along the turning gear (fig. 3–19). The coupling is held in either the disengaged or the engaged

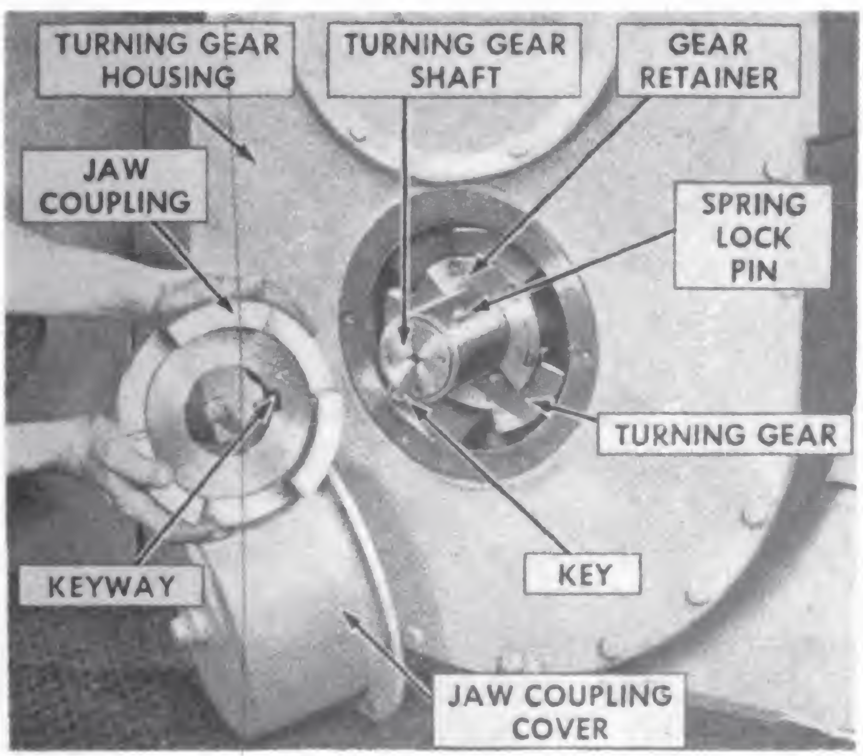


Figure 3–19.—Installing the jaw coupling on the turning gear.

position by a small spring-loaded pin in the turning gear shaft. The spring-loaded pin may be depressed with a screwdriver or small rod. To put the jaw coupling in place on the turning gear shaft, it is necessary to remove the welded steel cap on the end of the shaft. (The entire gear train of the turning gear is enclosed in a welded steel housing, doweled and bolted to the engine base and cylinder block. The welded steel cap is in turn bolted to the housing, directly over the turning gear shaft.)

When the handcrank is in position it engages a tapered shank on the worm gear shaft, shown in figure 3–20. (Note: Be sure to disengage the turning gear and remove the handcrank before attempting to start the engine.) The steel worm gear is secured on the shaft with a key. The worm gear engages a bronze worm wheel, which is, in turn, keyed to the pinion shaft. The pinion gear, also keyed to the pinion shaft, engages the large steel turning gear which floats on the turning gear shaft.

The pinion shaft rotates on ball bearings, supported by the turning gear housing and by the cover plate which is bolted to the housing. The turning gear shaft, bolted to the end of the engine crankshaft, carries both the turning gear and the three-jaw coupling. The turning gear is located axially on the turning gear shaft by means of a bronze retainer, bolted to the hub face of the gear, and rides in a groove on the shaft.

When the coupling moves axially along the shaft, driving power is obtained through a key which is held in the keyway of the shaft by two screws. (The coupling has a keyway which permits it to slide along the shaft.)

Lubricating oil is supplied to the bearing on the floating gear through holes drilled in the crankshaft and the turning gear shaft. A pipe plug with a $\frac{1}{4}$-inch hole is threaded into the end of the crankshaft to restrict the flow of oil. The forward ball bearing of the pinion shaft and the two ball bearings on the worm gear shaft are lubricated with grease, supplied through grease fittings.

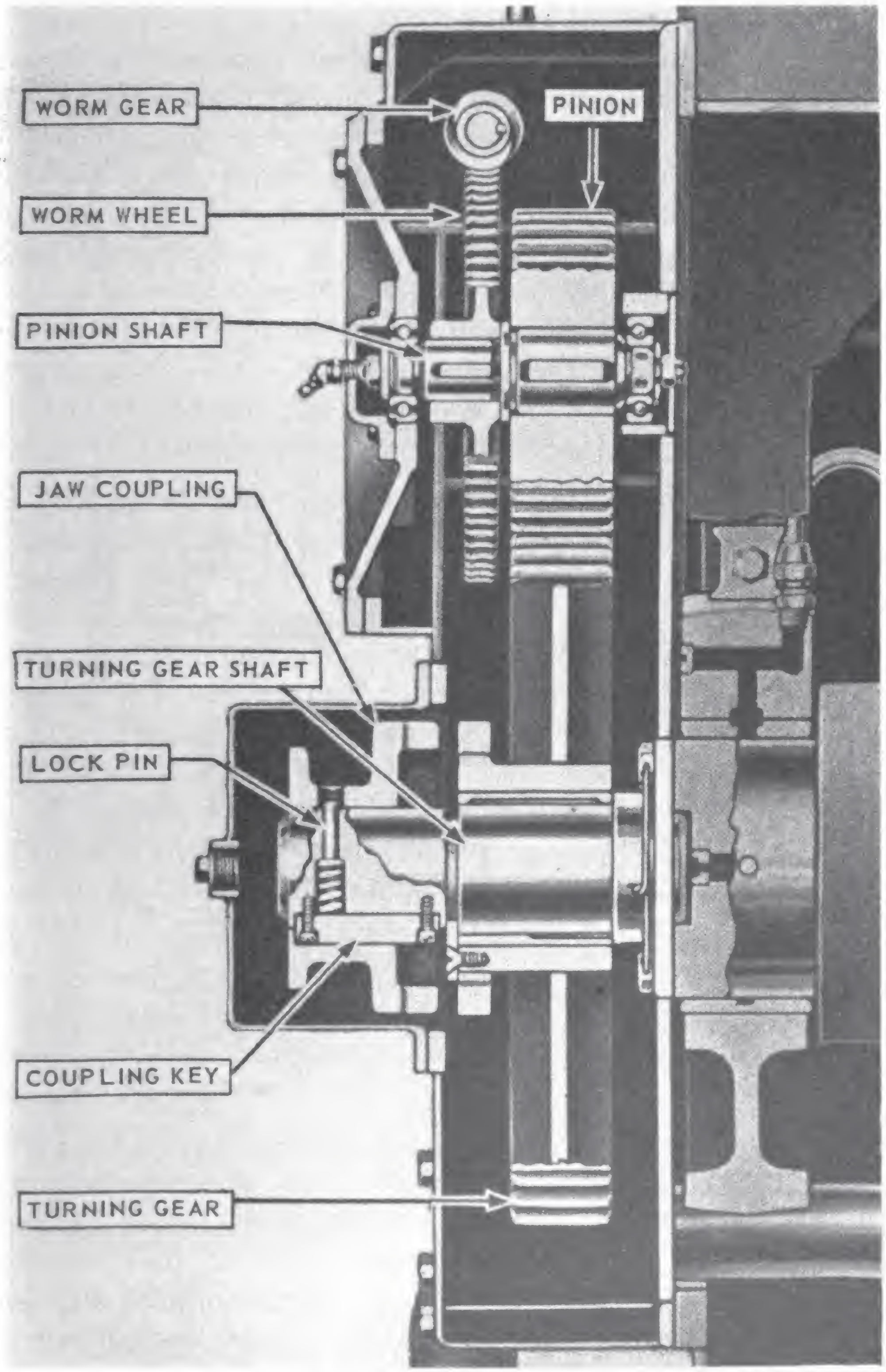


Figure 3–20.—Sectional view of crankshaft turning gear.

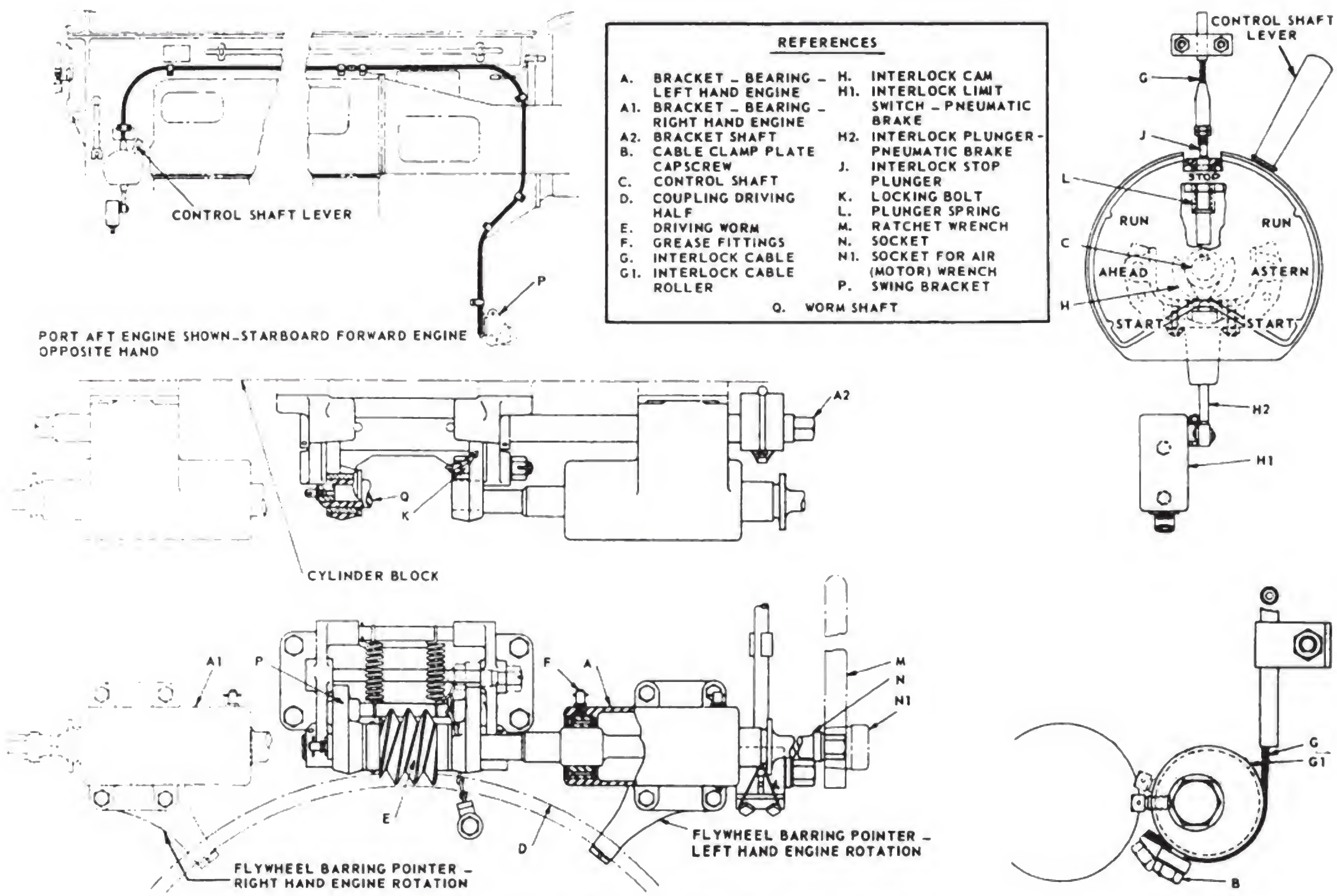


Figure 3–21.—Barring device and interlock.

However, some engines, such as the Fairbanks-Morse opposed-piston engine, are equipped with a mechanical barring (jacking) device, as shown in figure 3–21. The mechanical barring device is located on the crankshaft flexible coupling, operating through a helical worm gear. The driving worm gear (E) is mounted on a swing bracket (P) which holds the worms out of mesh, except during operation. As an additional safety feature, the swing bracket is held "out-of-mesh" position by a locking bolt (K). The interlock cable roller (G1) is mounted on the bracket shaft (A2) and holds the interlock stop plunger (J) up so that the interlock cam (H) and the control shaft (C) can be moved by the starting lever.

To operate the barring device (fig. 3–21), remove the locking bolt and lower the swing bracket by turning the bracket shaft (A2) until the driving worm is meshed with the coupling driving half (D). Slide the socket (N) over the end of the worm shaft (Q) and rotate the engine by turning the socket with the ratchet wrench (M). Disengage and replace the locking bolt. When the driving worm is meshed with the coupling driving half, release the stop plunger to provide a stop for the interlock cam and control shaft so that the worm gear cannot be damaged by an attempted engine start.

The interlock cam also actuates the pneumatic brake on the propeller shaft, when the engine is to be reversed. The interlock plunger (H2) trips the limit switch (H1) to interrupt the electrical circuit to the solenoid coil at the propeller brake.

The barring device can also be operated by an air (motor) wrench, shown in figure 3–22, using the socket and the socket driver to turn the worm shaft of the device. When an air hose is attached to the hose connection, and the line handle turned, air is admitted to the rotary valve and cylinders, revolving the crankshaft through the connecting rods. The crank pinion meshing with the spindle gear revolves with the spindle.

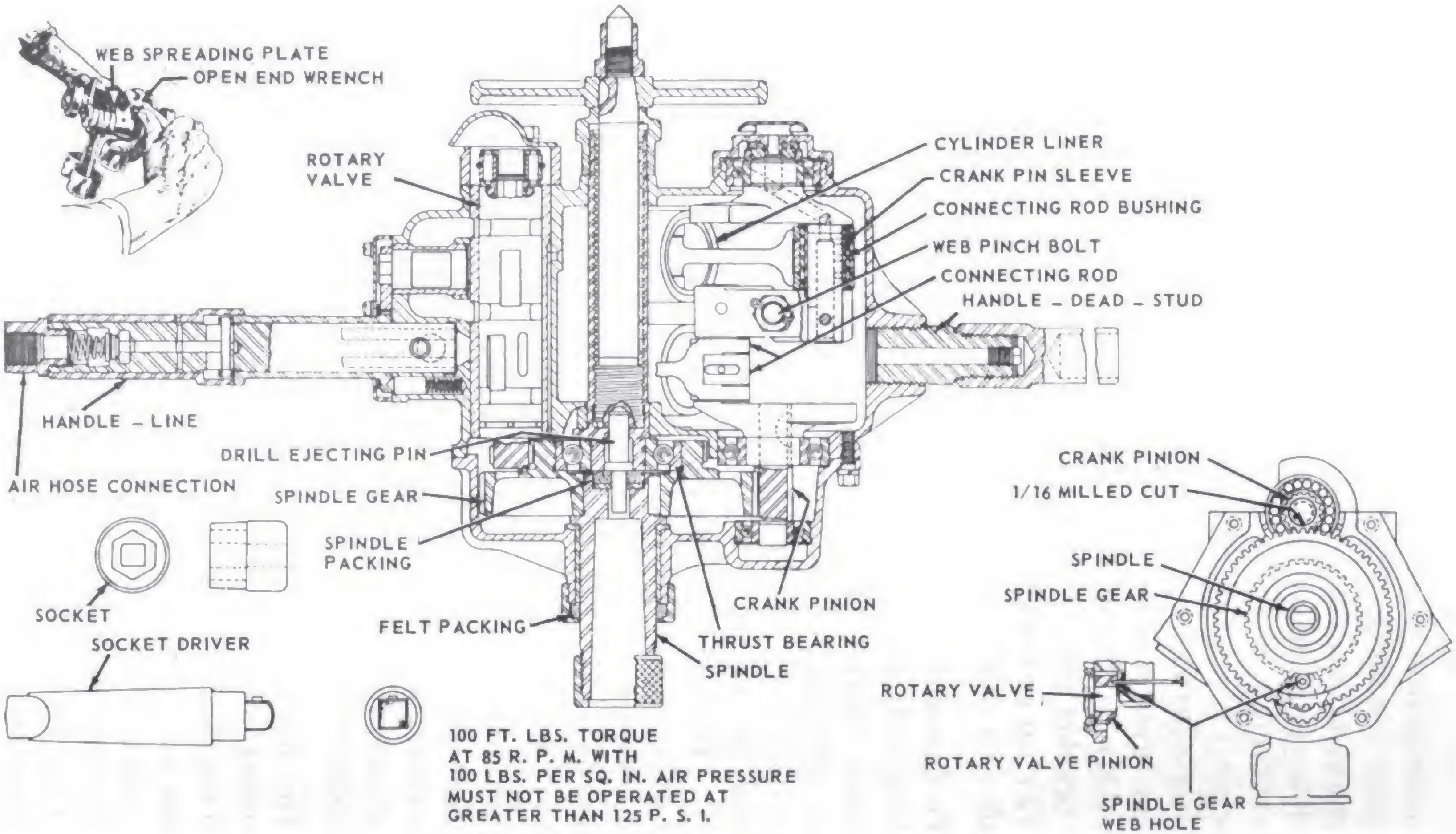


Figure 3–22.—Air (motor) wrench and socket for barring the engine.

THRUST BEARINGS

A propeller exerts a thrust on a ship which it is driving through the water. The axial thrust through the propeller shaft has to be taken up somewhere along the shaft, and a thrust bearing is generally installed at the forward end.

In the reduction and reverse gear units described in this chapter, a thrust bearing is mounted in the gear box. This is the usual setup on smaller ships. The most widely used is the Kingsbury thrust bearing.

A two-shoe Kingsbury thrust bearing is shown in figure 3–23. (The upper shoe is removed in this illustration.) The bearing consists of a thrust collar on the propeller shaft and two stationary thrust shoes, one on either side

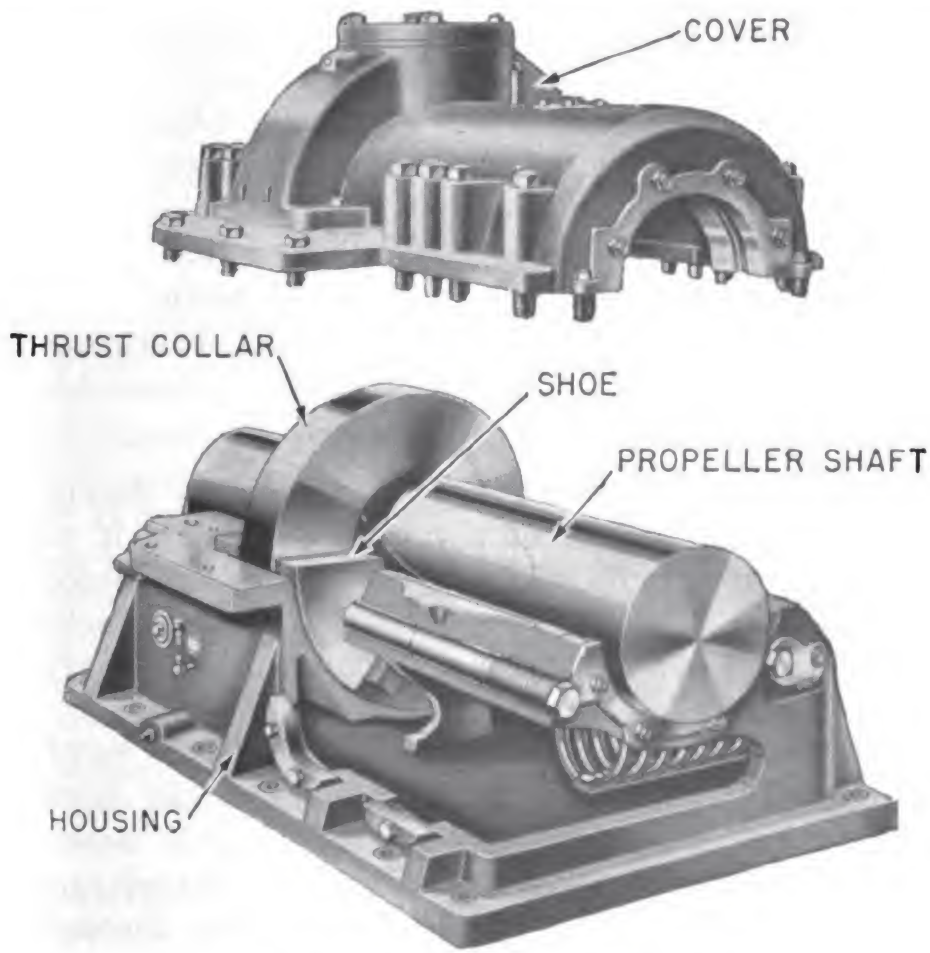


Figure 3–23.—Kingsbury thrust bearing.

of the collar. The shoes are adjustable and secured to the bearing housing, which is fixed to the ship's frame. Any forward or astern thrust on the shaft is taken up by the bearing and transmitted to the ship's structure. The collar and shoes are pressure-lubricated and run in a bath of oil. It is most important to have the collar pressure equally distributed on the shoes, and to use the proper grade of lubricating oil. Detailed information concerning the maximum and minimum allowable oil clearances on thrust bearings may be obtained from either the manufacturers' instruction books or plans.

VARIABLE PITCH PROPELLERS

Some naval vessels are provided with variable pitch propellers. With this arrangement, no reversing gear mechanism is required because the direction of propeller thrust can be changed without a change in its direction of rotation. The ship can be made to go ahead or astern by simply changing the pitch of the propeller blades.

Instructions regarding the limitations of engine speeds at different propeller pitches have been issued to all vessels equipped with variable or controllable pitch propellers. In addition, the special operating and maintenance instructions for these propellers should be consulted before any overhaul or repairs are undertaken.

SUMMARY

The clutches and couplings used in Navy marine installations will seldom be a source of trouble if proper operating and maintenance procedures are followed. It is advisable to follow the appropriate manufacturer's instructions when operating and maintaining a particular unit.

Learn to recognize the symptoms which are helpful in identifying abnormal conditions which may occur in clutches and couplings, and in the various associated gears. Become familiar with the causes of such troubles and learn how to prevent their occurrence through the application of proper procedures.

QUIZ

1. What are the two general styles of friction clutches?
2. What type of clutch assembly is used with the Gray Marine Diesel engine?
3. Why is there no shifting of the gears of the Gray Marine transmission mechanism?
4. When is the sliding sleeve of the twin-disk clutch assembly forced backward?
5. The forward and reverse disks of a twin-disk clutch are separated by what unit?
6. What happens when the operating lever of the Joe's clutch and reverse gear assembly is thrown forward?
7. How is lubrication of Joe's clutch and reverse gear mechanism accomplished?
8. If the clutch of a Joe's reverse gear assembly requires adjustment at frequent intervals, what procedure should be taken?
9. Why is it necessary to adjust the brake band more frequently than the metallic disks of a Joe's reverse gear assembly?
10. What are four possible causes of friction clutch slippage?
11. When a friction clutch is being overhauled, what should be done if a small nick appears in a bearing surface?
12. If a friction clutch is engaged while racing the engine, what will result?
13. If no spring tester is available when a nonadjustable friction clutch is being disassembled, how can the condition of the compression springs be determined?
14. What should be used to clean the clutch facings of a dry type friction clutch in which the clutch actuating mechanism is made of rubber?
15. What is the probable result if the adjusting device on an adjustable friction clutch is tightened to compensate for excessive wear on linings?
16. If a friction clutch "freezes" when the actuating mechanism is operating properly, what is the probable trouble?
17. If molded-type clutch linings are found to be stuck because of moisture, what procedure should be taken to eliminate the moisture?
18. What is the principal cause of clutch chatter?
19. Why is a steel spacer used to bolt the clutches of an airflex clutch and gear assembly to the engine flywheel?

20. What is the purpose of the air orifice of an airflex clutch mechanism?
21. If the four-way valve of an airflex clutch mechanism is in the forward position, the entire forward air system will remain at what pressure?
22. If the four-way valve is in the forward position and the bridge signals you to reverse the propeller, why is it necessary to pause for two or three seconds at neutral?
23. If the header and driver of an airflex clutch mechanism are worn and noisy, what must be done?
24. To prevent the operation of the clutches when the air pressure falls below the safe operating level, what unit is installed in the air line of an airflex clutch?
25. In general, what is the source of trouble when a quick-dump type hydraulic coupling slips excessively while under load?
26. What is the best way to prevent a hydraulic coupling from dumping while under load?
27. If the pressure relief nozzles of a quick-dump hydraulic coupling become clogged during operation, how can the nozzles be cleared without securing the engine?
28. What device is sometimes used with a friction clutch to eliminate slippage?
29. If difficulty in engaging a dog clutch is intermittent, what is the probable cause?
30. If there is too much oil on the sump and the reduction gear churns and aerates the oil, how is temperature affected?

CHAPTER 4

DIESEL-ELECTRIC DRIVES

This chapter will present selected information on Diesel-electric drives and equipment.

The design of the Diesel engine used with an electric drive installation is essentially the same as that used with gear or direct drives. The operating principles and procedures for Diesel engines will not be discussed in this training course, since they are covered thoroughly in *Engineman 3,* NavPers 10539.

TYPES OF DIESEL-ELECTRIC DRIVES

There are two types of Diesel-electric drive used aboard Navy ships: Diesel-electric d-c drive, and Diesel-electric a-c drive. Adaptability of these types to various horsepower requirements and their application to naval surface ships are discussed in the following paragraphs.

Diesel-Electric D-C Drive

This type of drive is best suited for submarines and surface ships in the low or medium horsepower range (up to approximately 6000 shaft horsepower). It has been installed in approximately 175 escort vessels and 500 surface vessels of other types, including minesweepers, submarine tenders, fleet and harbor tugs, fuel oil tankers and barges, rescue and salvage vessels, net-laying ships, ferry boats, and miscellaneous unclassified vessels.

Diesel-Electric A-C Drive

This type of drive is usually best suited for medium horsepower installations (ranging from approximately

4000 to 12,000 shaft horsepower). Its use has been limited to one submarine tender, USS *Sperry*, which is a 10,000-ton, twin-screw vessel, with 11,800-shaft horsepower.

ADVANTAGES AND LIMITATIONS OF DIESEL-ELECTRIC DRIVES

Compared with direct or gear drives, the principal advantages of electric drive are:

1. RELIABILITY OF OPERATION.—Since d-c electric drive propulsion installations are equipped with multiple generating sets and propulsion motors, the failure of an individual unit does not largely affect the over-all speed of operation of the ship. In addition, servicing and maintaining several small-capacity units of duplicate design can be accomplished more effectively than can the servicing and maintenance of a single large-capacity unit.
2. EASE OF OPERATION.—With electric drive equipment, control functions can be reduced to a minimum, and, when desired, remote control can be readily furnished. In addition, greater maneuverability may be easily obtained, by switching electrical connections for speed changes and for propeller reversal, without altering the direction of rotation of the prime mover.
3. LESS VIBRATION OF THE PRIME MOVER.—Torsional vibrations originating in the propeller are not transmitted to the prime movers.
4. ADAPTABILITY TO OTHER SERVICES.—In addition to supplying propulsive power, the generating sets may be used to supply electric power for other ship services.
5. FUEL ECONOMY.—At reduced power, fuel economy is obtainable from the use of electric drives, because some of the generating units that are not needed can be shut down completely; this reduces friction losses as well as permits the Diesel engines and generators to operate at more efficient loads.

6. REVERSAL OF ELECTRICAL CONNECTIONS.—The need for reversible Diesel engines is eliminated because, with electric drives, the direction of rotation of the propellers is reversed by electrical means.

Compared with direct or gear drives, the chief disadvantages of electric drive are as follows:

1. The installation is heavier, more expensive, and generally requires more over-all space.
2. The over-all efficiency is generally lower because of losses in generators and motors.
3. The use of electric drive equipment may increase hazards such as the possibility of fires in the equipment and injury to personnel from electrical shock.
4. Electric drive requires a greater variety of spare parts.

TRANSMISSION CHARACTERISTICS OF A-C AND D-C DRIVES

Most a-c installations provide one fixed speed ratio between the Diesel engine and the propeller shaft. The speed of the propeller is controlled by changing the speed of the engine.

In d-c installations, the ratio between the speeds of the Diesel engine and the propeller can be varied, over a considerable range, by changing such factors as the number of generators connected in the propulsion loop, the generator field current, and the motor field current. Because d-c systems are more flexible than a-c systems, they have been widely used for tugs, net tenders, and other types of ships which require a high degree of maneuverability.

DIESEL-ELECTRIC D-C DRIVE FOR SURFACE VESSELS

In order to ensure reliability and flexibility of operation, a minimum of two propulsion generators and two propulsion motors are provided for each propeller shaft. In surface vessels, the generators and motors of a single propulsion plant are connected in series, in a closed ungrounded loop, as shown in figure 4–1.

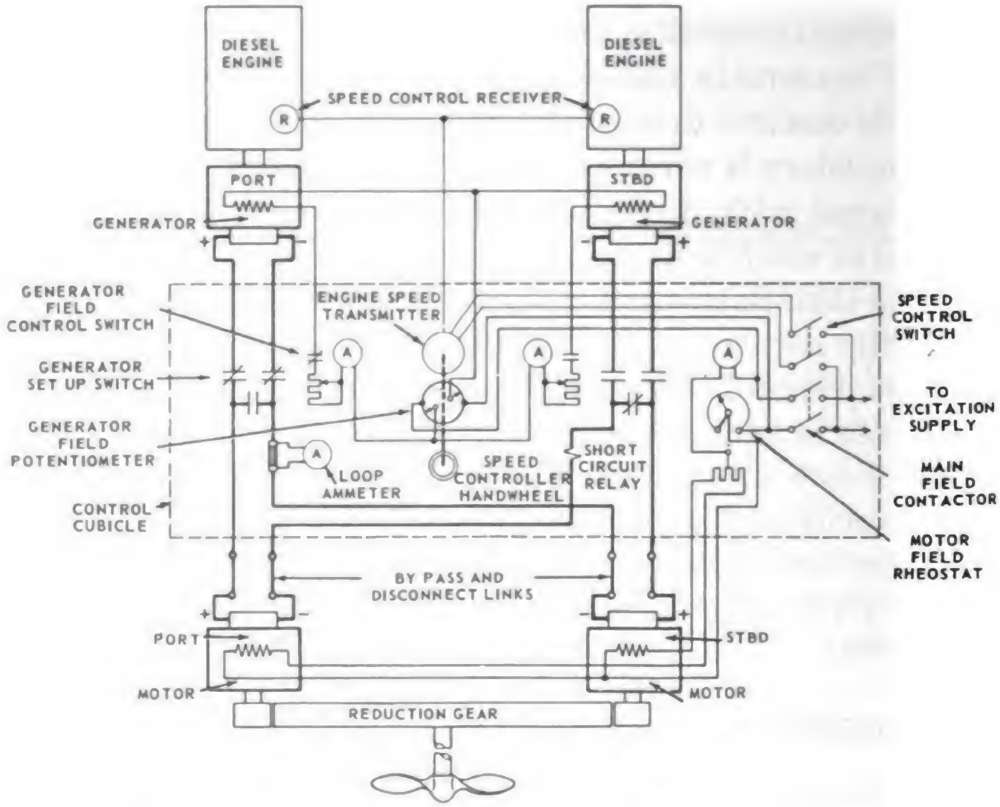


Figure 4–1.—Line diagram of typical Diesel-electric d-c drive.

D-C Propulsion Equipment

The essential constituents of a Diesel-electric d-c drive include one or more Diesel-driven generators, one or more propulsion motors, a source of current for excitation purposes, and control equipment.

The Diesel engine drives the generator. Since the direction of rotation of the propeller shaft is controlled by electrical means, the engine is required to run in one direction only; therefore, no engine-reversing gear is needed.

GENERATORS AND EXCITERS.—The generators, directly coupled to the Diesel engines, are shunt-wound d-c units. The exciting current necessary to control the generator output may be furnished by a small, belt-driven, d-c generator (exciter) or from M-G sets. Since the exciter must deliver a constant voltage while the engine speed

varies, a voltage regulator is required for the attached exciters. The capacity of the exciter will generally be greater than the power required for excitation so that current may be supplied, when needed, for operating auxiliaries.

PROPULSION MOTORS.—The d-c propulsion motors are also shunt-wound units. Current required for excitation purposes is furnished by the small generator or the M-G set mentioned in the preceding paragraph. When connected directly to the propeller shaft, the motor must be able to operate at slow speeds. This necessitates the use of a comparatively large motor; a double-armature, slow-speed motor is generally used. In some installations, however, reduction gears are placed between the motors and the propeller shaft (fig. 4–1). This arrangement eliminates the need for large, heavy motors and usually results in less over-all weight.

Control of D-C Propulsion Equipment

The variable-speed control system permits the control of both the propeller rpm and the direction of rotation of the propeller, by varying or reversing the generator field excitation. The control equipment is generally operated by a speed controlled handwheel on the propulsion control cubicle. (In most installations, a remote control lever is provided in the pilot house.) The handwheel is connected to a rheostat (or potentiometer) and reversing contacts, used to control the magnitude and the direction of the generator field current.

In addition, the handwheel is connected to an engine-speed transmitter which controls the engine speed. The transmitter, which may be mechanical, pneumatic, or electrical, is connected to individual receivers mounted on the Diesel engines and linked to their governors. The latter units maintain the speeds of the engines within relatively constant limits. The speed transmitter controls the governor setting and, therefore, the engine speed of the generating sets in service in one propulsion loop.

Some installations are also provided with individual vernier governor transmitters which furnish a fine adjustment, over a limited range of each engine governor. This makes it possible to equalize the engine speeds when the main control does not produce exactly the same effect on all engines.

For the ship to get under way, the speed controller is turned in a clockwise direction (from the "OFF" position) for "Ahead" rotation of the propeller shaft. Conversely, when the speed controller is turned in a counterclockwise direction (from the "OFF" position) for "Astern" rotation of the propeller shaft, the direction of the current in the generator field is reversed and causes the propulsion motors to rotate in the opposite direction. If the controller is moved beyond the full generator-field-excitation position, the engine-speed transmitter increases the speed of the Diesel engines.

Operation of D-C Propulsion Installations

Although Electrician's Mates are generally responsible for the operation, maintenance, and repair of electrical propulsion equipment, there may be times when you, as an Engineman, will be required to operate this equipment. Therefore, you should be familiar with the operating instructions and safety precautions which must be observed before starting, when starting, while under way, and when securing. Detailed instructions concerning the procedures for operating specific units of propulsion equipment can be found in appropriate manufacturers' instruction books. Additional information can also be found in chapter 41 (Section IV) of BuShips *Manual.*

BEFORE STARTING d-c electric propulsion installations, the following precautions should be observed:

1. Disengage the jacking gear.
2. Disconnect the heaters in the propulsion motors and generators to be operated.
3. See that separately driven lubricating oil pumps are in operation and the alarm systems have been tested.

4. See that the CO_2 fire extinguishing equipment is available and in satisfactory condition.
5. See that loose objects (tools, waste, etc.) are not left in the machinery, or on machine parts.
6. Check the control cubicles and the panels to make certain that no tools, waste, and loose gear are left therein. In addition, see that the protective screens and grids are in place.
7. Do not force the switches closed against the action of the mechanical interlocks.
8. Do not apply rated voltage to electrical windings having a very low insulation resistance, except in an emergency, before drying out, or repairing, and rechecking the resistance.
9. Do not start any equipment if there are indications of defective parts or if maintenance work is in process.

WHEN STARTING the d-c propulsion plant, the following procedure should be observed:

1. Close the necessary switches on the ship's service switchboards and on the power panels supplying the motor-driven auxiliaries and the propulsion control boards. Where normal and alternate power supplies are available, both supply lines should be energized up to the transfer switches in order to allow rapid transfer from normal to alternate supply. When selecting the normal supply, see that the transfer switches remain closed.
2. Open or close the necessary valves in the lubricating oil and circulating water systems. Bypass the oil coolers until the oil temperature reaches about 100° F, unless the coolers are automatic.
3. Start the motor-driven lubricating oil pumps, water pumps, blowers, excitation motor-generator sets, and other auxiliaries required. In installations where lubricating oil pumps are driven from either the Diesel engines or the reduction gears, use the standby lubricating oil pumps or the hand pumps to

circulate oil until the normal lubricating oil pumps are operating. Carefully observe the initial operation of the auxiliaries for any faulty operation (for instance, leakage of oil or water; or too rapid rise in bearing temperature). Take proper steps to remedy any troubles.

4. If propulsion motors and generators are equipped with surface type air coolers, open the vent cocks until all air has escaped. Restrict the flow of water through these coolers until the equipment has warmed up slightly; otherwise moisture may condense on the outer surface of the cooler tubes.
5. Place all lubricating oil pressure alarm systems and high water temperature alarm systems in normal service.
6. Start the Diesel engines and carefully check the initial operation, in accordance with engine operating instructions.
7. Check the circulation of the lubricating oil at the bearings. The oil flow through the sight glasses should be continuous. If the generator bearings are self-lubricated, examine the oil level in the wells. Inspect for oil leakage at the bearings.
8. Close the switches which energize the excitation and control bus. Then check the polarity and the voltage. (When starting cold, the no-load voltage of the exciters may be 5 to 10 percent above the rated value. An adjustment is generally NOT necessary until the equipment has been operating and warmed up.)
9. If remote control is available, close the engineroom-pilot house transfer switch, to select the desired control station.
10. Close the switches energizing the engine-speed control circuits.
11. Check the operation of the engine-speed controller, at all control stations, and see that the generator

setup switches are not in the PROPULSION position. Then move the speed controller about $\frac{3}{4}$ of its travel in the "Ahead" and "Astern" directions. See that all engines accelerate uniformly and operate at the same speed. Return the speed controller to the "OFF" position.

12. Close the control switches energizing the propulsion motor circuit and the generator field excitation circuit. Observe the reading of the motor field ammeter.
13. Close all other control switches.
14. Check the terminal voltage across each generator. (This voltage should be practically zero, but a voltage of 10 to 15 volts may exist because of residual magnetism.)
15. Connect the propulsion generators to be used into the series loop by operating the generator setup switches. If these switches are interlocked with the corresponding generator field control switches, open the latter control switches before operating the corresponding setup switches.
16. Turn the field rheostat to the proper setting for the number of Diesel-generator sets in service.
17. Obtain permission to test the motors and, when ordered by the bridge, move the engine-speed controller several steps, first in the "Ahead" direction and then in the "Astern" direction. (This test may be omitted during emergencies, if it is impracticable.)
18. Report ready condition to the appropriate officer.
19. Operate the speed controller gradually and in accordance with orders from the bridge. Observe the reading of the series loop ammeter and carefully check the operation of the propulsion motors, reduction gears, and shafting.

WHILE UNDER WAY, the following precautions should be observed:

1. Do not idle the Diesel engines or operate them for long periods at light loads, except during emergencies.
2. Do not exceed specified ratings of equipment, except during emergencies and then for only as short a period as possible.
3. Do not operate equipment continuously at critical speeds.
4. If the engine-speed controllers have notched positions, do not leave the handwheels set between notched positions.
5. Do not allow excessive accumulation of water in the bilges, especially in heavy seas, if there is danger of flooding or wetting the electrical equipment.
6. Do not allow water (from vent outlets, open hatches, pipes, etc.) to drop or spray on electrical equipment.
7. If possible, maintain ambient temperature below 50° C (122° F) around electrical equipment, or operate at reduced power to compensate for high ambient temperatures in warm climates. During emergencies, exceptions may be necessary for limited periods. (If separately driven ventilating fans or blowers are used, see that they are operating when the propulsion generators or motors are in service.)
8. At periodic intervals, inspect the bearings, the commutators, the lubricating oils, and the circulating water systems. In addition, check the various temperatures for evidence of overheating.
9. Maintain a balanced load on the Diesel-generators and propulsion motors in service.
10. Keep the electrical windings and the commutators free of oil and water.
11. Keep the standby power supplies and the standby auxiliaries in readiness for immediate use.
12. If the engine stalls and the power supply from a propulsion generator is lost, move the generator setup switch to the "BYPASS" (or "OFF") position as

soon as possible. Readjust the motor field rheostat and the engine-speed controller.

13. If the cause of a trouble cannot be found when a casualty occurs or faulty operation is indicated, secure the defective equipment as soon as possible.
14. Lock in the circuit breakers only during emergencies or under battle conditions. One circuit breaker in each main supply line should be left unlocked, and personnel should be stationed to reclose the breaker if a trip-out results from mechanical shock.
15. Do not operate at high backing speeds if excessive vibration occurs or if the steering equipment is overloaded.
16. If a protective device operates, investigate the cause of the trouble before resetting the device.
17. If the electrical equipment is on fire, secure the equipment, deenergize the live circuits, and use CO_2 fire extinguishers. If possible, avoid using water or foam solutions on electrical equipment.
18. If the lubricating oil pressure alarm or the high water temperature alarm sounds, restore normal oil or water circulation immediately. If this is not possible, secure the affected equipment.
19. When operating with one shaft of a twin-screw installation idle, lock the idle shaft or supply sufficient lubrication to permit the propeller shaft to rotate freely without damage to the bearings.
20. In maneuvering, operate the engine-speed controller gradually and watch the instruments on the propulsion control board.
21. Do not place a propulsion generator into the series loop without first strengthening the motor field current.

WHEN SECURING Diesel-generators, the following steps should be taken:

1. Move the corresponding generator setup switches to "OFF" (or "BYPASS") before stopping the engine.

2. Turn on the heaters in the propulsion motors and generators to maintain a dry condition in the electrical windings after the units are secured.
3. Keep salt water drained out of oil coolers and air coolers when these coolers are not in use, especially in freezing weather.
4. Keep the bilges dry.
5. Check, clean, and inspect the equipment thoroughly after use, especially if it has been subjected to severe service.
6. Do not operate separately driven fans or blowers when the propulsion motors or generators are secured.

Procedures in Event of Operating Difficulties

In the event of a casualty to a component part of the electric propulsion plant, operate the standby units on alternate sources of power and notify the appropriate officer as soon as possible. After the cause of the trouble has been determined, take proper steps to correct the trouble and to prevent its recurrence.

As an Engineman, you may be required to operate propulsion equipment, particularly when a casualty arises. Therefore, you should be familiar with the following casualties, causes of failure, and procedures to be observed:

MOTOR-DRIVEN AUXILIARY FAILS TO START. If a motor-driven auxiliary fails to start when the "START" button is pushed, the possible causes of the failure and the procedure to be followed are:

1. The overload relay may be tripped. Push the "STOP" button and reset the overload relay by pushing the "RESET" button, then push the "START" button. By listening carefully, you may be able to determine whether the main contact has closed.
2. There may be no power to operate the motor. Check the distribution panel to determine whether power is available, and whether the switch to the auxiliary

is closed. If the normal source of power is dead and the alternate source of power energized, move the bus-transfer switch to connect the auxiliary to the alternate source of power.

3. The driven auxiliary or the rotor of its driving motor may be jammed. Test the equipment by turning the auxiliary manually; correct the trouble, if possible.

If the auxiliary is absolutely required and the preceding steps do not remedy the difficulty, use a standby unit.

In addition, the following equipment should be checked as soon as possible: the line and the control fuses, the electrical connections, the motor controller, the push-button stations, and the motor.

MOTOR-DRIVEN AUXILIARY STOPS WHILE UNDER WAY.—If a motor-driven auxiliary stops while under way, the possible causes of failure and the procedure to be followed are:

1. The motor may have stopped because of a temporary reduction in voltage; or the overload relay may have tripped. To remedy this trouble, push the "STOP" button, reset the overload relay, and push the "START" button. Watch the starting operation to see that the auxiliary accelerates to normal speed.
2. A circuit breaker in the power supply line may have tripped out because of either mechanical shock or momentary overload. Close the circuit breaker and restart, one at a time, the auxiliaries that do not restart automatically.
3. If the normal power supply is lost and cannot be restored immediately, transfer to an alternate source of power (if available). Restart the auxiliaries that do not restart automatically.
4. If the trouble cannot be easily located and remedied, or if it becomes necessary to use emergency methods to keep a motor-driven auxiliary in operation, start

and place a standby auxiliary in service; and disconnect the faulty unit as soon as possible.

5. The defective auxiliary should be thoroughly checked as soon as possible and cleaned, tightened, or overhauled as required.

UNEQUAL ENGINE SPEEDS.—The Diesel-generators in service should operate at the same speed, or within 10 to 20 rpm of each other. Small adjustments can be made easily if individual-vernier speed transmitters are installed. If these units are not installed, the engine-speed control receivers (or the governor mechanism) will have to be used to adjust engine speed.

If an idle Diesel-generator set fails to accelerate up to the speed of the other sets when it is placed in service, move the engine-speed controller to a lower setting, temporarily. This will generally synchronize the incoming generator with the other units. When the speed controller is in the "FULL AHEAD" position, the Diesel engines should operate at the maximum rated speed.

PROPULSION MOTOR CASUALTY. If a propulsion motor is damaged, proceed as follows:

1. Deenergize the propulsion loop and the excitation circuits completely.
2. If the motor is damaged electrically so that it is unable to carry current, but is free to rotate, proceed as follows:
   a. Shift the motor-disconnect links so as to bypass the motor armature. Do not short circuit the armature of the defective motor.
   b. Disconnect the motor field leads at the control cubicle and tape the ends of the leads, if they are exposed.
   c. Decrease the number of Diesel-generators in service to correspond with the maximum normal power that can be delivered to the propulsion motors remaining in service.

d. Set the motor field controller in the "ON" position when all motors and all generators are in use.
e. Operate the motors which remain serviceable. Avoid operating at propeller speeds that may cause excessive vibration or overloads.

3. If the motor should not be rotated after the casualty, proceed as follows:
   a. Disconnect the motor, if possible, from the propeller shafting or from the reduction gear by removing the coupling bolts. Then lock the motor armature to keep it from being rotated or from being moved axially by the motion of the ship. If the motor cannot be disconnected (as in twin-screw installation), lock the *propeller shaft.*
   b. Disconnect the electrical leads and observe the instructions mentioned in paragraph 2 above.

In geared motor installations, the locking means employed should be secured to the propeller shaft or to a coupling. In gearless, tandem motor installations the locking device should be placed aft of the after propulsion motor. The device should not be placed on a shaft or on a coupling, either of which is located on the high-speed side of a reduction gear or between the two motors in the tandem installation. The locked shaft should not be used until repairs have been made to the motor or some means has been provided to disconnect the motor from the shaft.

DIESEL ENGINE FAILURE.—If a Diesel engine loses power and stalls, or tends to reverse, proceed as follows:

1. Remove the associated propulsion generator from the series loop as soon as possible.
2. Adjust the motor field rheostat and the engine-speed controller on the Diesel-generators remaining in service.
3. Reset the engine fault relay, if installed.
4. Investigate and correct the trouble before returning the Diesel-generator to service.

If the trouble cannot be easily located and remedied, put an alternate Diesel-generator set (if available) in service.

If the required propeller speed cannot be maintained without overloading the available Diesel-generator sets, notify the appropriate officer as soon as possible.

OVERHEATING OF MOTOR AND GENERATOR BEARINGS.—Permissible operating temperatures for bearings can generally be found in manufacturers' instruction books. Bearing and lubricating oil temperatures must be determined by thermometer readings. Oil-lubricated bearings will operate most satisfactorily in the 140° to 160° F temperatures range; 180° F is the safe maximum limit. Operating records and personal experience will help you to determine the approximate normal operating temperatures and the rates of temperature rise to be expected. If a bearing temperature increases more rapidly than normally expected, or if the normal temperature for the bearing is exceeded, the following steps should be taken:

1. Check the circulation and the temperatures of the lubricating oil and the cooling water.
2. Observe whether the oil pressure is normal and the flow of oil through the sight glasses continuous.
3. See that the air vents are not clogged and that the oil rings are not sticking.
4. Check the lubricating oil for the presence of water or other foreign matter.
5. See that the equipment is not overloaded.
6. If the cause of the trouble is not determined, increase the rate of flow of oil or of cooling water to clear the clogged lines and to carry off additional heat.
7. If the bearing temperatures continue to rise and are approaching dangerous limits, notify the engineer officer and the officer of the deck. If permission is granted, slow down the equipment. If this action checks the temperature rise, continue to operate at the reduced speed and try to find the trouble.

8. If slowing down the equipment fails to remedy the trouble, shut down the equipment before the maximum permissible temperatures are exceeded. A complete check of alignment and of bearing clearances should be made, and, if necessary, the entire lubrication system should be inspected and cleaned.

In emergencies, continued operation of hot bearings is made possible by cooling the bearings temporarily. When shutting down equipment because of excessive bearing temperatures, rotate the shaft slowly until the bearing has cooled sufficiently to prevent freezing of the bearing metal to the shaft.

SUMMARY

Modern Diesel-electric installations are generally provided with d-c drives because they are more flexible and more efficient than any other type of electric drive.

As an EN 2, you should be familiar with the propulsion plant equipment aboard your ship. You should know how to start, operate, and secure Diesel-generators. In addition, you should know how to handle operational casualties. Detailed information regarding the operation of specific installations may be obtained from manufacturers' instruction books; additional information may also be obtained from BuShips *Manual.*

QUIZ

1. What type of electric drive is best suited for submarines and surface ships of low or medium horsepower range (up to approximately 6000-shaft horsepower)?
2. At reduced power, why is fuel economy better in electric drives than in gear drives?
3. How is the speed of the propeller controlled in a-c installations?
4. Why is a minimum of two propulsion generators and two propulsion motors provided with Diesel-electric d-c drive installations?
5. What type of motor is generally used in d-c installations where the motor is directly connected to the propeller shaft?

6. What two factors are controlled by varying or reversing the generator field excitation of an installation?
7. How is engine speed maintained within relatively constant limits?
8. What procedure should be taken when the engine stalls and the power supply from a propulsion generator is lost while under way?
9. If the cause of a trouble, resulting from a casualty, cannot be found while under way, what should be done?
10. If the electrical equipment is on fire, while a ship is under way, what procedure should be taken?
11. If a temporary reduction in voltage or the tripping of an overload relay causes a motor-driven auxiliary to stop while under way, what steps should be taken to remedy the trouble?
12. What should be done if an idle Diesel-generator set fails to accelerate up to the speed of the other sets when it is placed in service?
13. If a propulsion motor is damaged, what step must be taken immediately?
14. If a propulsion motor should not be rotated after a casualty has occurred, and cannot be disconnected from either the shaft or the reduction gear, what should be done?
15. What step should be taken immediately after a Diesel engine loses power and stalls?
16. If the required propeller speed cannot be maintained without overloading the available Diesel-generator sets, what step should be taken?
17. What is the maximum safe temperature at which oil-lubricated bearings can operate?
18. If the bearing temperatures continue to rise to a maximum limit and the cause of the trouble has not been determined, what step should be taken?
19. When shutting down equipment because of excessive bearing temperatures, why should the shaft be rotated slowly while the bearing cools?

CHAPTER 5

PUMPS

Aboard ship, pumps are the most numerous units of auxiliary machinery. Faulty operation or maintenance, improper lubrication, and neglect to observe safety precautions are the major causes for pump failure. As an EN 2, you will be responsible for making minor adjustments and operational repairs to pumps.

This chapter deals primarily with the operation and maintenance of reciprocating pumps, rotary pumps, and centrifugal pumps. Additional information on specific types of pumps may be obtained from BuShips *Manual,* Chapter 47, and appropriate manufacturers' instruction books.

Before proceeding with this chapter, however, you should have a general knowledge of the basic operating principles of the various types of pumps. It may be helpful for you to review this subject matter in the Navy training course, *Fireman,* NavPers 10520–A.

RECIPROCATING PUMPS

Although the majority of pumps installed on modern ships are the centrifugal or rotary types, the reciprocating direct-acting, double-acting, simplex, vertical pump (fig. 5–1) is still used as secondary fire-and-flushing, or bilge pump on many Navy ships. In addition, it is used as an emergency and feed pump. The reciprocating pump is used as an emergency pump because it is reliable for start-

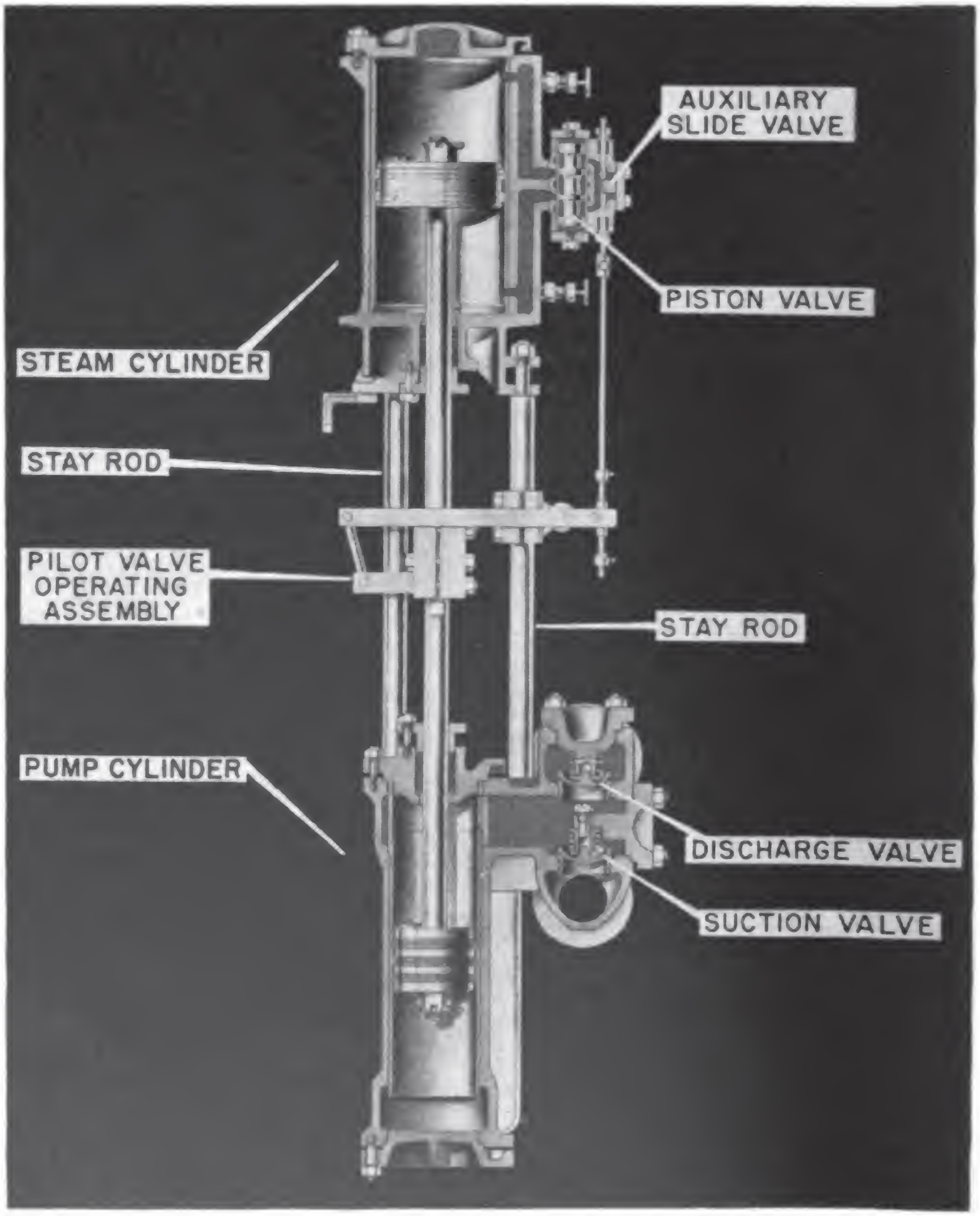


Figure 5–1.—Reciprocating pump.

ing under cold conditions. In addition, it is easy to operate and can be started safely by relatively inexperienced personnel.

Construction of Reciprocating Pumps

The power end of a reciprocating pump consists of a bored cylinder, generally made up of cast steel or composition, in which the steam piston reciprocates. The cylinder

is fitted with heads at each end; one head has a stuffing box to allow for movement of the piston rod. Steam inlet and exhaust ports connect each end of the steam cylinder with the steam chest. Drain valves are installed in the steam cylinder, so that water resulting from condensation may be drained off.

Cushioning valves are fitted in the top and bottom of the cylinder on some pumps. These valves can be adjusted to trap a certain amount of steam at the end of the cylinder; therefore, when the piston reaches the end of its stroke, it is cushioned by the steam and prevented from hitting the end of the cylinder. When the pump is oper-

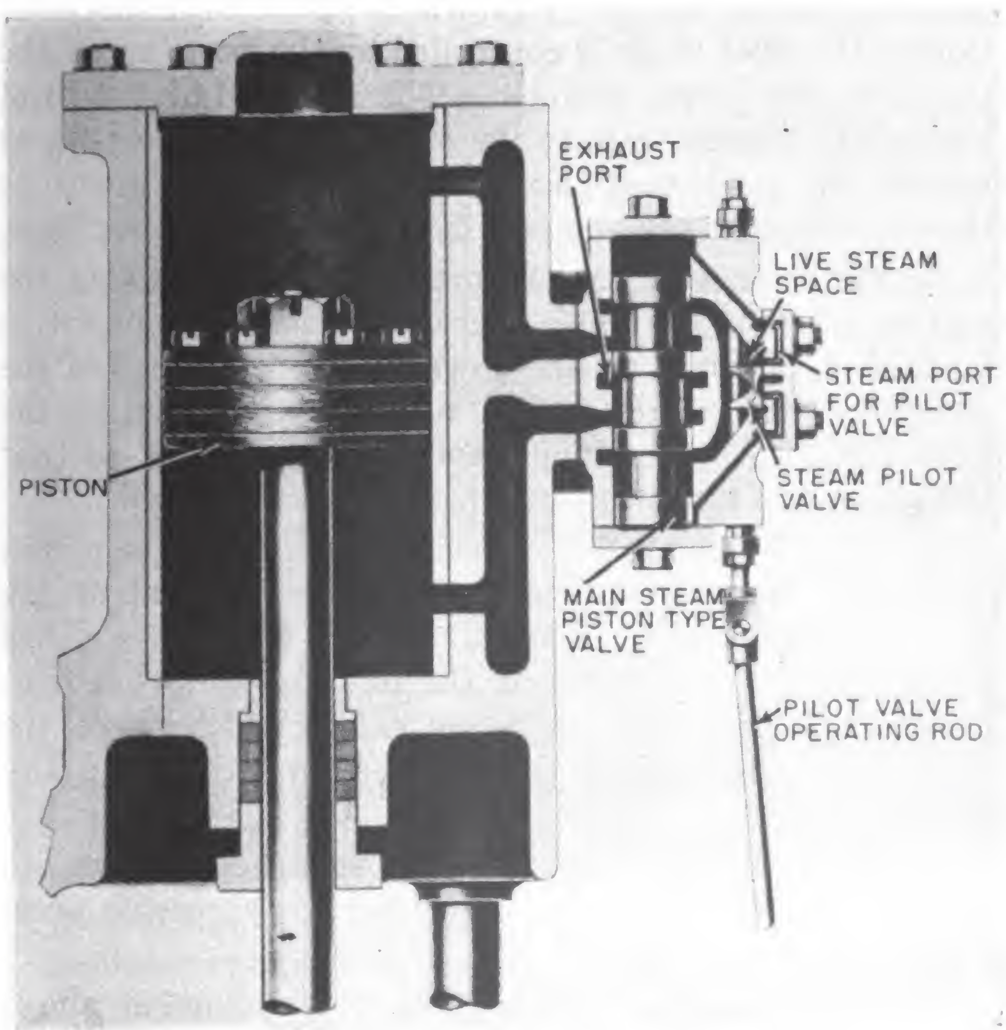


Figure 5-2.—Piston-type valve gear.

ating at high speeds, the cushioning valves should be nearly closed so that a considerable amount of steam will be trapped at each end of the cylinder; at low speeds, the cushioning valves should be almost open. (The steam cylinder shown in figure 5–2 does not have cushioning valves.)

Automatic timing of the admission and release of steam to and from each end of the steam cylinder is accomplished by various types of valve arrangements. The modern reciprocating pump is equipped with piston-type valve gear, as illustrated in figure 5–2, which consists of a main piston-type slide valve and a pilot slide valve. Since the rod from the pilot valve is connected to the pump rod by a valve-operating assembly, shown in figure 5–3, the position of the pilot valve is controlled by the position of the piston in the steam cylinder. The function of the pilot valve is to direct steam to the main valve (piston) so as to shift the position of the main valve, to admit steam to the top or bottom of the steam cylinder at the proper time.

As the crosshead arm (sometimes referred to as the rocker arm) of the valve-operating assembly, shown in figure 5–3, is moved up and down by the movement of the pump rod, the moving tappet slides up and down on the pilot valve rod. The tappet collars are adjusted so that the pump will make the designed full stroke.

The liquid end of a reciprocating pump has a piston (plunger) and cylinder assembly similar to that of the power or steam end. The valve chest, sometimes called a water chest, is attached to the liquid cylinder; it contains the suction and discharge valves which serve the upper and lower ends of the cylinder, on both the up and down strokes.

A relief valve is fitted to the discharge chamber, to protect the pump and the piping against excessive pressure.

Some reciprocating pumps have an air chamber and a snifter valve installed in the liquid end. The upper part

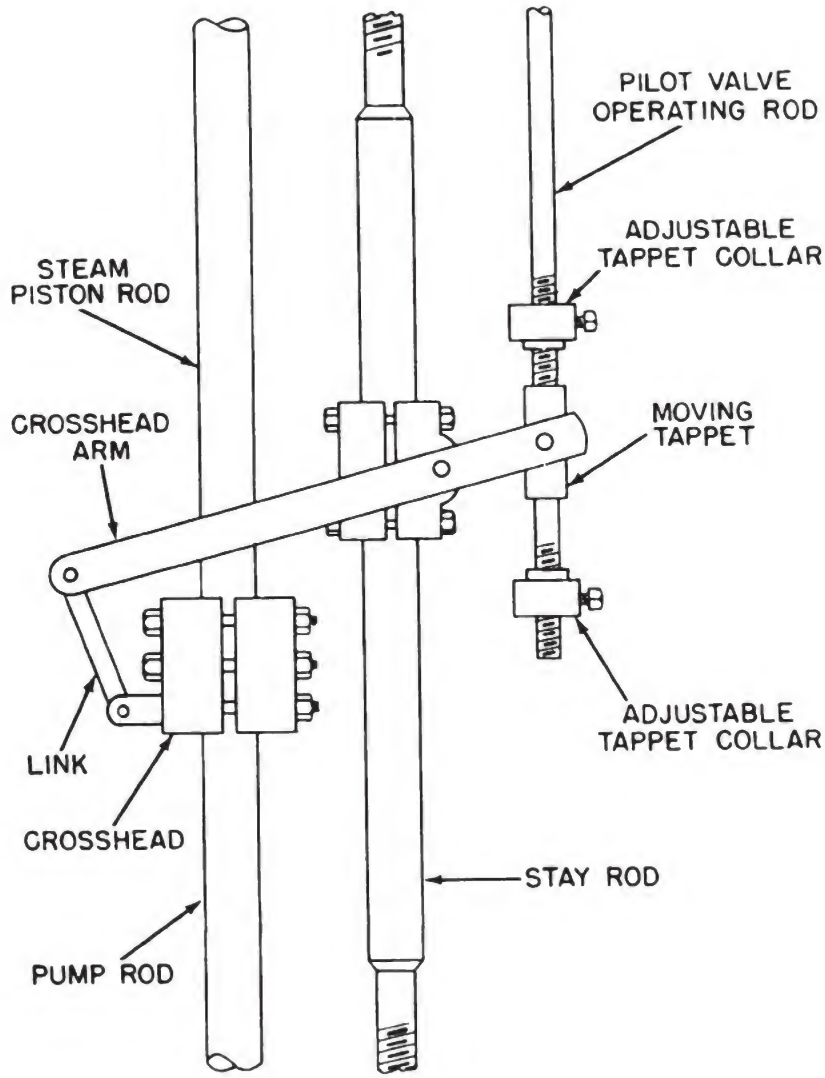


Figure 5-3.—Valve-operating assembly.

of the air chamber contains air, the lower part water. On each stroke, the plunger exerts pressure which compresses the air in the chamber. When the plunger stops at the end of a stroke, the air in the chamber expands and allows a gradual drop in the discharge pressure. (The air chamber, therefore, smooths out the discharge flow, absorbs shock, and prevents pounding.) The snifter valve, if installed, allows a small quantity of air to be drawn in and compressed with each stroke. If no snifter valve is installed, some provision is usually made for charging the air chamber with compressed air.

Method of Designating Pump Size

The standard way of designating the size of a reciprocating pump is by giving three dimensions in the following order: (1) the diameter of the steam piston; (2) the diameter of the pump plunger; and (3) the length of the stroke. For example, an 8 x 6 x 7 reciprocating pump has a steam piston which is 8 inches in diameter, a pump plunger which is 6 inches in diameter, and a stroke of 7 inches.

Operating a Reciprocating Pump

When a reciprocating pump is to be operated for the first time, after an overhaul, or after the ship has been dry-docked, the following steps should be taken:

1. Check the alignment of the pump, and, if necessary, correct it. Operating a pump that is out of line will result in scoring of rods and liners.
2. See that the steam and liquid lines are free from scale and other foreign matter.
3. Check all the packing and repack, if necessary.
4. Move the rods of the steam pilot valve, by hand, to make certain that the pilot valve moves easily.
5. Check all connections and fittings to ensure that they are tight.

However, the general procedure for STARTING a reciprocating pump is as follows:

1. Oil the pins of the steam valve operating gear and set up on all the grease cups, if fitted.
2. Open the liquid end suction and discharge valves.
3. Open the exhaust and steam line root valves.
4. Open the top and bottom cylinder drain valves, and steam chest drain valves.
5. Open the steam exhaust valve at the pump.
6. Crack open the steam throttle valve and admit steam slowly so that the steam cylinder will warm up gradually.

7. Close the steam cylinder drains after the pump makes a few strokes, and the cylinder is clear of water.
8. Open the throttle valve sufficiently to bring the pump up to the desired operating speed or discharge pressure. If the pump is controlled by a pressure governor, open the throttle gradually until the governor takes control of the pump, and then open the throttle valve fully.
9. Adjust the cushioning valves, if fitted, until an adjustment is obtained that permits silent and smooth operation of the pump, i.e. sufficient pump speed at the end of the stroke without knocking.

In general, the steps to be followed in STOPPING AND SECURING a reciprocating pump are as follows:

1. Close the steam throttle valve.
2. Close the steam exhaust valve at the pump.
3. Open the steam cylinder, and the valve chest drains.
4. Close the liquid end suction and discharge valves.
5. Close the steam and the exhaust root valves (cutout valves).

Adjustment of Stroke

In order for a reciprocating pump to operate properly, the piston should travel a little beyond the top and bottom counterbore; this means that the pump must operate with the full length of stroke. A full stroke ensures a more even wear throughout the cylinder. (The position of the piston in relation to the top counterbore is shown in figure 5–4.)

A stroke indicator is generally provided on reciprocating pumps as an aid in checking the length of the stroke. The indicator consists of a pointer secured to the piston rod crosshead, and two marks on one of the cylinder tie rods. The upper mark should line up with the pointer on the crosshead when the piston is at the upper end of the stroke; the lower mark should line up with the pointer when the piston is at the lower end of the stroke.

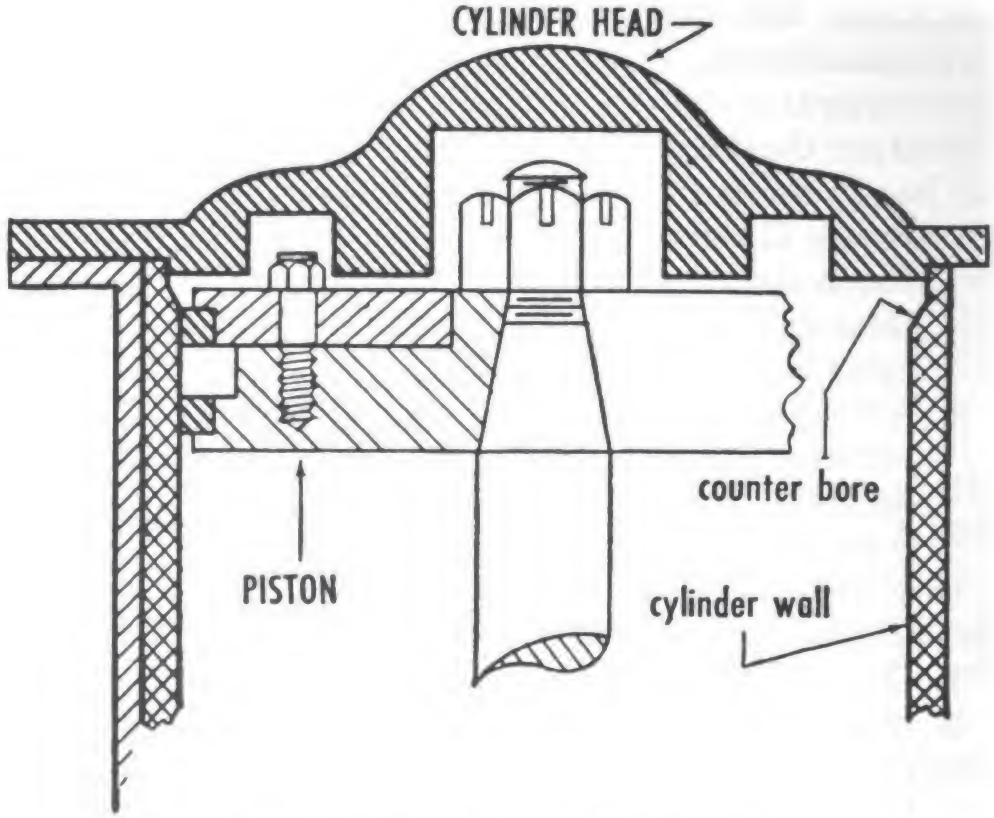


Figure 5–4.—Piston at upper end of stroke.

When a pump does not have full stroke, something is wrong with the adjustment. Continued operation with a short stroke will cause the shoulders to be worn in the cylinders with resultant breakage of rings and followers. These shoulders will have to be removed before full stroke can be obtained. Too long a stroke, or insufficient cushioning, is usually indicated by a heavy metallic knock in the steam cylinder and should be corrected at once.

Properly adjusted valves will ensure a full stroke for the various pump loads and speeds. For detailed information concerning the proper method for setting specific types of valve gear, you should refer to the manufacturer's drawings and instruction books. However, when detailed information is not available, the following is a satisfactory method for setting steam valves. Place the piston and the auxiliary valve on the center, or on half stroke. Then move each collar from the tappet ½ the

width of the steam port. If the tappet moves the full distance of the stroke, the distance from the collar to the tappet will be ½ stroke (steam port opening). Then start the pump, and, if the stroke is too short, the collars should be screwed farther apart. (If both collars are not moved equal distances from the tappets, the stroke will be longer on one end than on the other.) After the final adjustment has been made, lock the collars securely in place.

At times the steam valves of a duplex pump will have to be adjusted. Place number two piston on its top striking point, and after removing the steam chest cover of the valve chest of number one piston, adjust the slide valve securing nuts so that there is an excess of ⅛ inch full port opening to the bottom end of the cylinder. Make sure that the upper tappet collar is bearing on the tappet. (In some cases, it may be necessary to drain the liquid end of the pump in order to jack the pistons up or down.)

To set the valve for number two piston, move number one piston to its top striking point, and follow the same procedure as above.

To test whether the adjustment is satisfactory, crack the throttle and run the pump slowly, against little or no pressure, and with the cushioning valves (if fitted) wide open. If the valves are properly adjusted, the pistons should be striking on the cylinder heads. If the pistons do not make a complete stroke after the adjustment has been made, a tight piston rod and plunger packing may be causing binding. The cause of the trouble should be determined immediately. (If cushioning valves are fitted at each end of the steam cylinder, the valves should be closed until the pump runs at full stroke, of both steam pistons, with smoothness of reversal and no striking. If it is not possible to obtain this smoothness of reversal, it may become necessary to slightly alter the adjustment of the valve operating collars.)

Troubles and Remedies

Since there may be times when operating difficulties with reciprocating pumps will result, some of the most common causes of trouble, together with their remedies, are mentioned in this section of the chapter.

FAILURE TO START. There may be times, after you have lined up the pump and cracked open the throttle valve, that the pump won't kick over. You may proceed to open the throttle a little wider, but still nothing happens. You may repeat the starting procedure, determine that everything has been done correctly, and find that the pump doesn't operate. At this point, proceed as follows:

1. Secure the pump. Do not adjust the tappet collars.
2. Examine the discharge and exhaust lines for closed valves, or for a valve disk that has become detached from the stem. If no valves are closed, the plunger or the steam piston may be frozen, especially if the pump has been idle for some time.
3. Jack the pump with a bar to determine if there is excessive friction.
4. Disconnect the auxiliary valve stem from the operating gear, without changing the position of the tappet collars. Open the exhaust, suction, and discharge valves, and then crack the throttle. Work the auxiliary valve by hand. If the packing is not seizing the stem, the valve should work freely by hand.
5. If the pump still fails to start, secure it. Remove the steam valve chest cover and examine the main piston valve to see if it has overridden or stuck.
6. If the pump cannot be started, a complete overhaul of the working parts of the steam end will probably be necessary to stop steam leakage, the most probable cause of the trouble.

FAILURE TO TAKE SUCTION. If the pump fails to take suction, the operation will be jerky. To correct this trouble, proceed as follows:

1. See that all stop and check valves in the suction line are open, and the line has no obstructions.
2. If the pump has a suction lift (as a bilge pump), it may be necessary to prime the pump before it will take suction. Salt-water pumps can usually be primed from the sea by opening the sea suction valve for a short interval.

LOSS OF DISCHARGE PRESSURE. When a pump loses discharge pressure, the trouble is usually due to a leaky plunger; to a leaky, broken, or stuck valve in the water end; or to air being admitted through open or leaky valves in the suction line. Stop the pump as soon as practicable, and trace and correct the trouble. If a pump has been operating properly and loses pressure on one stroke, look for a broken valve immediately. If there is a broken valve, it should be replaced. Great loss of efficiency results from leaky suction and discharge valves, and from leaky plungers. (Previous experience with a particular type of pump may be taken as a guide in deciding where to look for the trouble. Under normal conditions, the first investigation should be of the most accessible parts.)

POUNDING IN THE LIQUID END. This trouble can be caused by improper cushioning, too heavy valves, or a loose piston. This pounding can be stopped by proceeding as follows:

1. Adjust the steam cushioning valves.
2. Examine the pistons to see that they remain tight on the rod.
3. Examine the piston rod where it is secured in the crosshead, for lost motion.
4. Look for a loose nest of valves or loose zinc plates, if fitted.

If the pump is not fitted with an air chamber on the suction side and pounds, a snifting valve installed on the suction side usually stops the pounding.

To stop pounding in the water end of a pump having a considerable suction head, proceed as follows:

1. Slow down the pump, since pounding usually results from water hammer or ram effect in the suction piping.
2. See that the air chamber is properly charged.

GROANING IN THE WATER END. This is usually due to the packing being too tight, but may be caused by a broken follower, or by a stuck valve. In this case, stop the pump and examine it immediately, as failure to do this may result in a scored cylinder.

GROANING IN THE STEAM END. This is usually due to an excessive ring pressure against the cylinder walls, to broken piston rings, or to the misalignment of cylinders. Unless this trouble is immediately corrected, the cylinder walls will become scored. In addition, rust may cause groaning, in the steam end, when a pump is started after a long period of idleness.

KNOCKING IN THE STEAM CYLINDER. This trouble may be caused by loose piston rings, a loose piston on the rod, or by some maladjustment of the piston-type valve gear. The pump should be stopped at once so that the trouble may be found and corrected.

ERRATIC OPERATION. When a reciprocating pump sticks in any part of the stroke, or stops frequently (with the throttle valve opened the proper amount), the cause is in the steam end. The trouble probably results from one or more of the following defects:

1. LOST MOTION IN THE OPERATING GEAR DUE TO WEAR. This trouble should be remedied by rebushing, and, if necessary, by renewing the pin at the affected part.
2. LEAKAGE OF STEAM BY THE MAIN OR THE AUXILIARY VALVE, DUE TO WEAR OF EITHER VALVE. This trou-

ble can be remedied by refacing the flat face of the slide valve on its seat.

3. LEAKAGE OF STEAM BY, OR STICKING OF, THE VALVE CHEST PISTON. In order to stop this, it may be necessary to rebore the valve chest cylinder, or at least renew the auxiliary piston rings.

4. EXCESSIVE LEAKAGE BY THE STEAM PISTON RINGS. In this case, it may be necessary to renew the rings, or rebore the steam cylinder, or both. Where split rings are fitted, however, the leakage can be partly stopped by removing the rings and peening them so as to increase the wall pressure. When cylinders are rebored, over-size pistons and rings should be fitted.

5. SMALL PORTS AND PASSAGES IN THE VALVE CHEST STOPPED UP WITH SCALE. This frequently occurs on new vessels because of failure to blow out all scale from the steam lines before the parts are connected.

Maintenance and Repair

Reciprocating pumps, like other equipment, require routine maintenance and occasionally, some repair work. This chapter covers some of the most important points dealing with routine maintenance and repair of reciprocating pumps. Additional information may be obtained from chapter 47 of BuShips *Manual* or manufacturers' instruction books.

The pins of the valve-operating assembly should be kept well oiled. However, you must NOT attempt to lubricate the steam or water cylinders, the valve chest, or the piston rod. (A slight GLAND LEAK-OFF is all the lubrication that rods and stems require.)

Piston rod packing should be renewed whenever it becomes worn or dried out. In this case, a little routine maintenance can save a great deal of work, since it is much easier to renew packing than to replace rods.

Because of corrosion, salt water pumps require special maintenance. Approximately every six months the internal parts of the liquid end should be examined and cleaned. If zincs are installed, they should be inspected once a month and replaced when necessary.

Before repairing or examining a pump, assemble all the pertinent blueprints, drawings, and available data. These drawings and data will give you the required clearances, measurements, information regarding materials to be used, and other important data. In addition, you should have the complete history of the pump being repaired, so that you will know what has been done previously, when repairs were made, and what kind of trouble has been encountered with this particular pump.

Whenever reciprocating pumps are opened for repairs, micrometer or caliper measurements should be taken of the main cylinders and the valve chest cylinders. These measurements are made on the fore and aft and athwartships diameters at the top, middle, and bottom. The results should be recorded on the Machinery History Card, with an accompanying diagrammetric sketch showing the measurements obtained and the date on which they were made.

Remember that the steam end of a reciprocating pump should NOT be dismantled until a thorough check reveals that the water end is satisfactory. Most reciprocating pump troubles, however, result from fouled water cylinders, worn valves, or from faulty conditions in the pipe connections external to the pump.

SCORED WATER CYLINDER. When a water cylinder becomes scored, it is not always necessary to rebore or renew the liner. Slight scoring of the cylinder walls can be corrected by stoning. A water cylinder should not be rebored unless it is worn out of round, or has tapered beyond the maximum allowable amount, as tabulated in table B–5 of chapter 40 of BuShips *Manual*.

SCORES IN STEAM CYLINDER.—Scoring in a steam cylinder, even though of a minor nature, necessitates reboring to prevent steam leakage past the piston. The presence of such leakage is indicated by a dullness and discoloration of the cylinder walls. Once leakage has started, steam will gradually cut away cylinder walls until leakage past the piston becomes so excessive that it interferes with the proper operation of the pump.

LOOSE PISTONS. Pistons at the water end of pumps are generally constructed of cast iron and are of the body and follower type. The piston itself is not a tight fit, but depends upon several rings of fibrous packing to prevent leakage. These rings of packing are placed between a shoulder at one end of the piston and a follower plate at the other end. A water piston is shown in figure 5–5.

If a steam or water piston works loose on the rod, it is generally due to poor workmanship and assembly, or to the rod being so fitted that the shoulder bears against the piston without giving a proper bearing surface for the tapered part of the rod. When set up handtight, the piston should fit within 1/32 to 1/8 of an inch of the shoulder; it should then be forced tightly against the shoulder by the securing nut. However, the piston cannot be

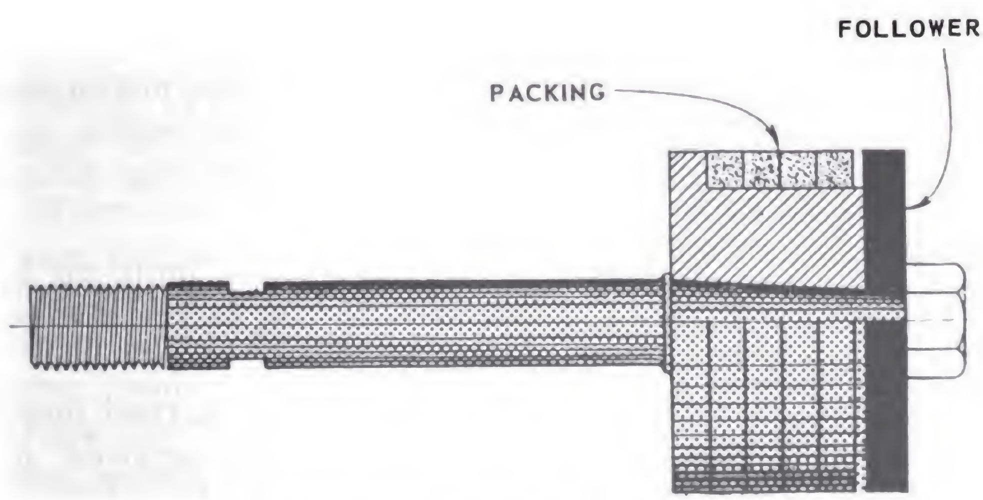


Figure 5–5.—Liquid plunger and piston rod.

brought firmly home unless all foreign matter has been removed from the taper of the rod. Piston trouble will usually disappear when the piston is properly refitted to the rod. (If a jamb nut or a split pin is not fitted, one should be installed.)

TESTING TIGHTNESS OF STEAM PISTON IN CYLINDER.—To test the tightness of the steam piston in the cylinder, proceed as follows:

1. Remove the cylinder head. Shore the piston to prevent forward or upward motion.
2. Connect a steam hose to the lower drain cock and gradually raise the pressure to the working pressure of the pump or the hose, whichever is less. If the rings are not tight, steam will leak past them. It must be remembered that this test shows defects for only that portion of the cylinder occupied by the piston. If measurements show that there is a great difference in size in various parts of the cylinder, the test should be repeated several times. During each test, the piston should be in a different part of the cylinder.

PISTON TOO SMALL.—Pistons may be built up by flowing on metal by the oxyacetylene method, by electric welding, or by metal spray. The piston is then machined to the proper fit.

It sometimes happens that in reboring a water cylinder you introduce so much clearance that the piston and the follower require renewal. Until a new piston and follower can be obtained, one of the following procedures may be used:

1. The piston and the follower may be built up by flowing on metal, and then turned to the correct diameter.
2. The piston and the follower may be turned down and threaded, and threaded rings screwed on tightly. Then machine the outside diameters of the rings to fit the cylinder.

Breaking of followers.—The breaking of followers and bolts may result from misalignment. This trouble may also result from screwed plugs in the piston working loose and coming adrift. When a piston is to be examined or repaired, make certain that the plugs are tight. The plugs should be prick-punched to prevent their backing-out.

When such trouble occurs in any one set of pumps on board ship, however, it may result from a weak follower. In this case, the Bureau of Ships should be notified so that the design may be improved and alterations authorized. (A new and heavier follower, or one of better material, can be tried on a pump to see if it stops the trouble. The breaking of followers can be prevented by drilling the piston for through bolts for securing the follower.)

When the follower is too small in diameter, plunger packing will frequently roll up between the piston and the cylinder, causing the follower to jam and break.

Renewing plunger packing.—Tuck's, flax, or other types of soft packing should be soaked in hot water for at least 12 hours before it is fitted and installed in a pump. In emergencies, however, when there is no time for soaking, the packing may be used without soaking if it is cut with enough clearance to allow for swelling. Failure to do this will cause the pump to groan, or may result in a scored cylinder.

Worn or broken piston rings.—Troubles in the steam cylinder result chiefly from faulty piston rings. Wearing of piston rings can cause a pump to lose power, and even, in some cases, to stop. If a pump stops, while operating slowly, in the middle of a stroke, the trouble may be due to worn rings. In this case, secure the pump and examine the condition of the rings and the cylinder. If necessary, renew the piston rings.

Figure 5–6 shows a steam piston assembly of a reciprocating pump. The piston rings are cast iron. If the piston rings are broken or worn or have been poorly fitted so that there is excessive leakage by the piston, new rings must be installed.

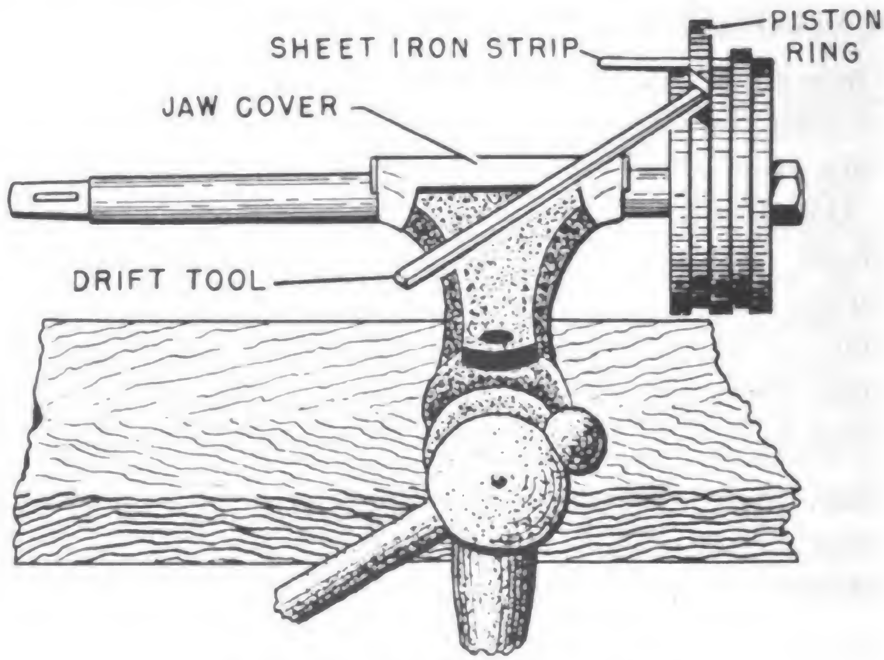


Figure 5–6.—Removing piston rings.

To remove a piston ring, hold the piston rod and piston in a vise, as illustrated in figure 5–6. (When doing this, use soft metal covers on the vise jaws to prevent digging into or otherwise abrading the polished surface of the piston rod.) Pry the end of the old ring by means of a thin, pointed drift tool and a strip of sheet iron or an old piece of hacksaw blade, as shown. Continue the prying and add more strips until the ring is raised out of its groove and can be slipped off the piston. (Rings of built-up pistons, however, can be removed by removing the follower plate studs and disassembling the piston.)

When the rings have been removed, take micrometer measurements of the cylinder or liner, to determine the exact diameter. In addition, measure the width of the

ring grooves in the piston to determine the width of the new rings. The inside diameter of the new ring can be determined either by obtaining it from one of the old rings or by checking the applicable blueprint. If you obtain the diameter from one of the old rings, place a piece of chart paper in the gap where the ring is cut, bind the ring so that the ends butt up snugly, and then measure the inside diameter.

When replacing piston rings, first fit the new rings to the cylinder to check the GAP clearance. If the gap clearance is not specified on the blueprint, allow a clearance slightly less than .001 of an inch per inch of cylinder diameter. For example, a clearance of .007 to .008 inch should be allowed for a piston ring of a 10-inch cylinder. If necessary, file the ends until proper clearance is obtained. The width of the rings should be checked, to make sure that they will fit into the grooves properly. If no clearance data is available, you can fit the piston rings by rolling them around the grooves. The rings should fit snugly, yet roll freely. If they do not, polish the sides of the rings lightly on fine emery cloth held against a smooth and even surface. Repeat the process until the rings fit properly in their respective grooves. (The ring gaps must be staggered so that they do not fall in one line.)

With split rings, the steam may force the rings out against the cylinder, causing the pump to groan, and to cut the cylinder and the rings. The remedy is to turn a groove approximately 1/32-inch and 3/8-inch wide about the middle of the ring and drill three or four 1/8-inch holes. This will relieve the steam pressure through the ring.

VALVES IN WATER END.—All valves in the water end of the pump must be kept tight to ensure satisfactory and economical pump operation. Cast valves may be faced off in a lathe and then ground in on their seats by a simple device consisting of a length of rod slotted to fit

a piece of metal which seats across the top of the valve. An ordinary bitstock can be used to do the grinding.

It is sometimes desirable to take a cut off the valve seat without removing it. A simple cutter can be made with an extension for a bitstock similar to the grinding-in device. When flat valves are fitted, the seats may be trued up by using a small surface plate and spotting in the section on the surface plate.

After the valves have been ground in, test the entire pump by closing the discharge valve, starting the pump, and checking the proper suction and discharge pressure.

At each examination, try all metal valve disks with a straightedge to see if they are true, and test the spring tension of the valves. Tension on the valve springs should be great enough to ensure a quick closing of the valve, but not so great that the valve cannot be lifted easily by hand. See that the springs are tightly secured by split pins, and adjust the valves to give the proper fit. The lift should be such that the circumferential opening is slightly greater than the clear opening through the seat, but NOT greater than 1/4 of the diameter of the opening.

Keep the valves clean; a light mineral oil makes a good cleanser, and a lye or soda solution is satisfactory for removing caked or gummed oil from the valves.

In pumps having valve seats secured only by a taper fit, the seats should be forced home by a jack resting on the end of a reseater which, in turn, rests on the face of the valve seat. If the seat works loose, peen the edge of the metal slightly. In pumps that have the valve seats screwed into the pump diaphragm, always insert the valve seats with white lead; otherwise it will be practically impossible to get them out.

Extreme care should be exercised in assembling pumps after overhaul. Mark valves, seats, stems, and springs before removal, so that you will be able to match them in sets for proper assembly.

IMPROPER ALIGNMENT.—This is one of the most frequent sources of trouble with pumps aboard ship. Pumps secured to a bulkhead are more subject to misalignment than those with independent bases and settings. A pump may have been properly aligned in the ship and then pulled out of line when bolted to the bulkhead; or, after the pump was secured, the ship may have changed shape sufficiently to warp the bulkhead and cause misalignment. Operation of an improperly aligned pump usually scores the rod and cylinders, and breaks the followers and bolts. Test the alignment of pumps occasionally by removing the piston and plunger and running a line through the cylinders. This should be performed as a routine test within the first year after a ship is commissioned; and also in the case of a pump that is scoring the rod or cylinders, or breaking followers.

Sometimes, when steam cylinder bulkhead mounting pad bolts are slacked off, the cylinder pad may pull away from the mounting as much as ½ inch, indicating settling of foundations and pump.

Before making an alignment check, you must check the mounting and holding-down bolts to see that they are tight.

The alignment of a reciprocating pump can be checked accurately by running a line from the lower end of the water cylinder to the top end of the steam cylinder, as shown in figure 5–7. To do this, fasten one end of the wire to the exact center of the bottom end of the water cylinder, and fasten the other end of the wire to a temporary beam at the top end of the steam cylinder. Then adjust the wire from the top end so that it runs through the center of the water cylinder. Check the location of the wire, with respect to the walls of the steam cylinder. If the wire does not go through the exact center of the steam cylinder, it indicates that the pump is out of alignment.

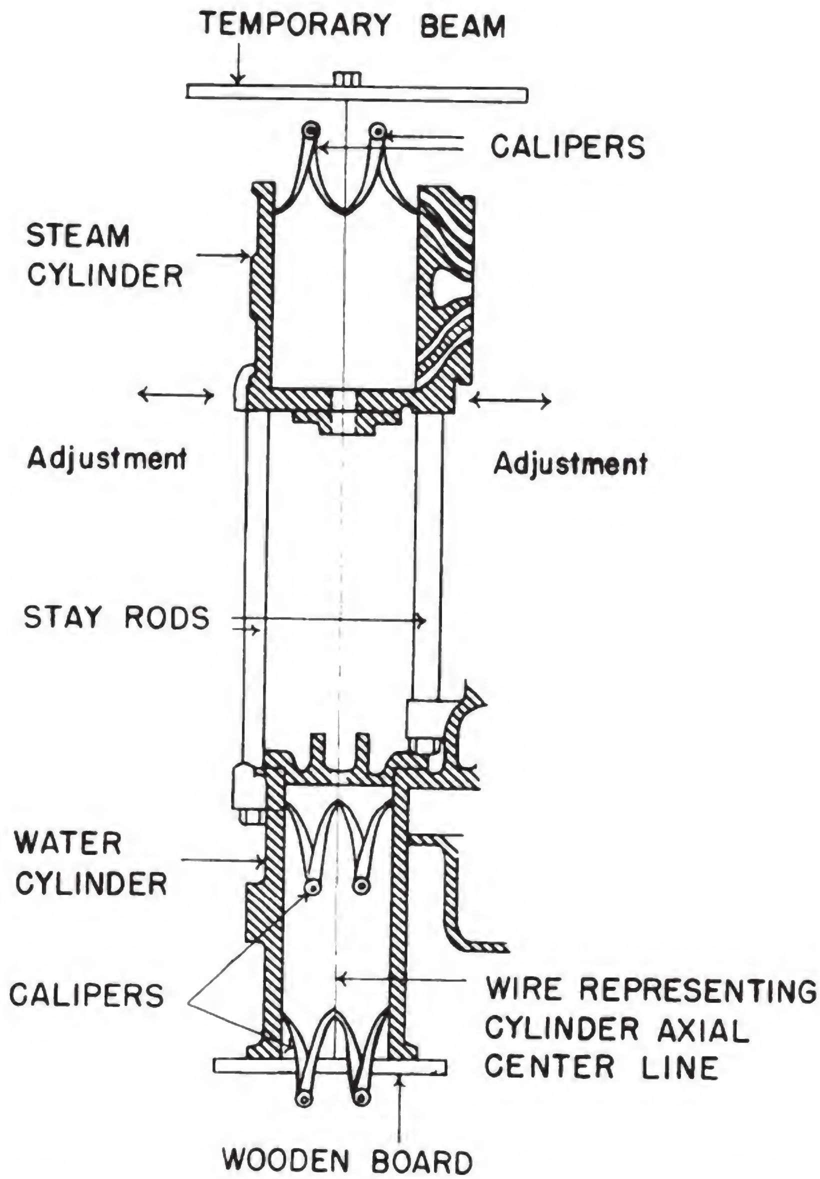


Figure 5–7.—Method of checking and adjusting pump alignment.

To align the pump, adjust the steam cylinder so that the entire length of the cylinder is centered on the wire.

Angular misalignment can be corrected by inserting shims either at the top or bottom of the stay rods. Lateral misalignment can be corrected by loosening the stay rod nuts and moving the steam cylinder to center on the wire.

To make a rough check of alignment of a pump, pull the steam and liquid end rod packing, and check the clearances between the piston rods and the cylinder head throat bushings. Make this check with the pistons in three positions—top, center, and bottom of the stroke. If the clearance is not uniform and the throat bushings are worn out of round, misalignment is indicated and an accurate alignment should be made as soon as practicable.

Misalignment may also result if the connection between the pump and the bulkhead mounting pads allows for no expansion. This condition can be corrected by elongating the bolt holes in the steam cylinder mounting pads, or by using mounting bolts $1/8$ inch smaller in diameter than the holes.

Tests for Reciprocating Pumps

The following tests should be conducted on reciprocating pumps:

1. Jack over all idle pumps by hand DAILY.
2. Move all pumps by steam or power WEEKLY.
3. Inspect liquid end valves, valve stems and springs; inspect steam valve gear for wear, and check setting of relief valves QUARTERLY.

Safety Precautions

The following safety precautions should be observed when operating and maintaining reciprocating pumps:

1. Never try to jack over a pump while the steam valve to the pump is open.
2. Before opening a steam cylinder or steam valve chest, see that the drains are open, and that the steam and exhaust root valves are wired closed.
3. Before opening the water cylinder or the valve chest of a pump handling water at a temperature in excess of 120° F, make certain that the suction and discharge valves are wired closed, and that the cylinder and the valve chest are drained.

4. Always open the steam cylinder drain valves when the pump is shut down, and leave them open until the pump is again in operation and has been cleared of condensate.

VARIABLE STROKE PUMPS

Variable stroke pumps are largely used on electrohydraulic steering gear, elevators, and cranes. Although they are generally classified as rotary pumps, they actually operate on somewhat the same principle as a single-acting reciprocating pump. A rotary motion is imparted to the pump by a constant-speed electric motor, but the actual pumping is done by a set of pistons reciprocating inside a set of cylinders. The way in which rotary motion is translated into reciprocating motion is explained and illustrated in *Fireman,* NavPers 10520–A.

There are two general types of variable stroke pumps commonly used aboard naval vessels. In the axial-piston type, the pistons are arranged parallel to each other and to the pump shaft; in the radial-piston type, the pistons are arranged radially from the shaft.

The AXIAL-PISTON VARIABLE STROKE PUMP, shown in figure 5–8, usually has either seven or nine single-acting pistons which are evenly spaced around a cylinder barrel. (Cylinder barrel, as used here, actually refers to a cylinder block which holds all the cylinders.) The piston rods make a ball-and-socket connection with a socket ring. The socket ring rides on a thrust bearing carried by a casting known as the tilting box (or tilting block).

When the tilting box is at a right angle to the shaft, and the pump is rotating, the pistons do not reciprocate; therefore, no pumping takes place. However, when the box is tilted (away from the right angle) the pistons reciprocate and the liquid is pumped.

When the variable stroke axial-piston pump is used as

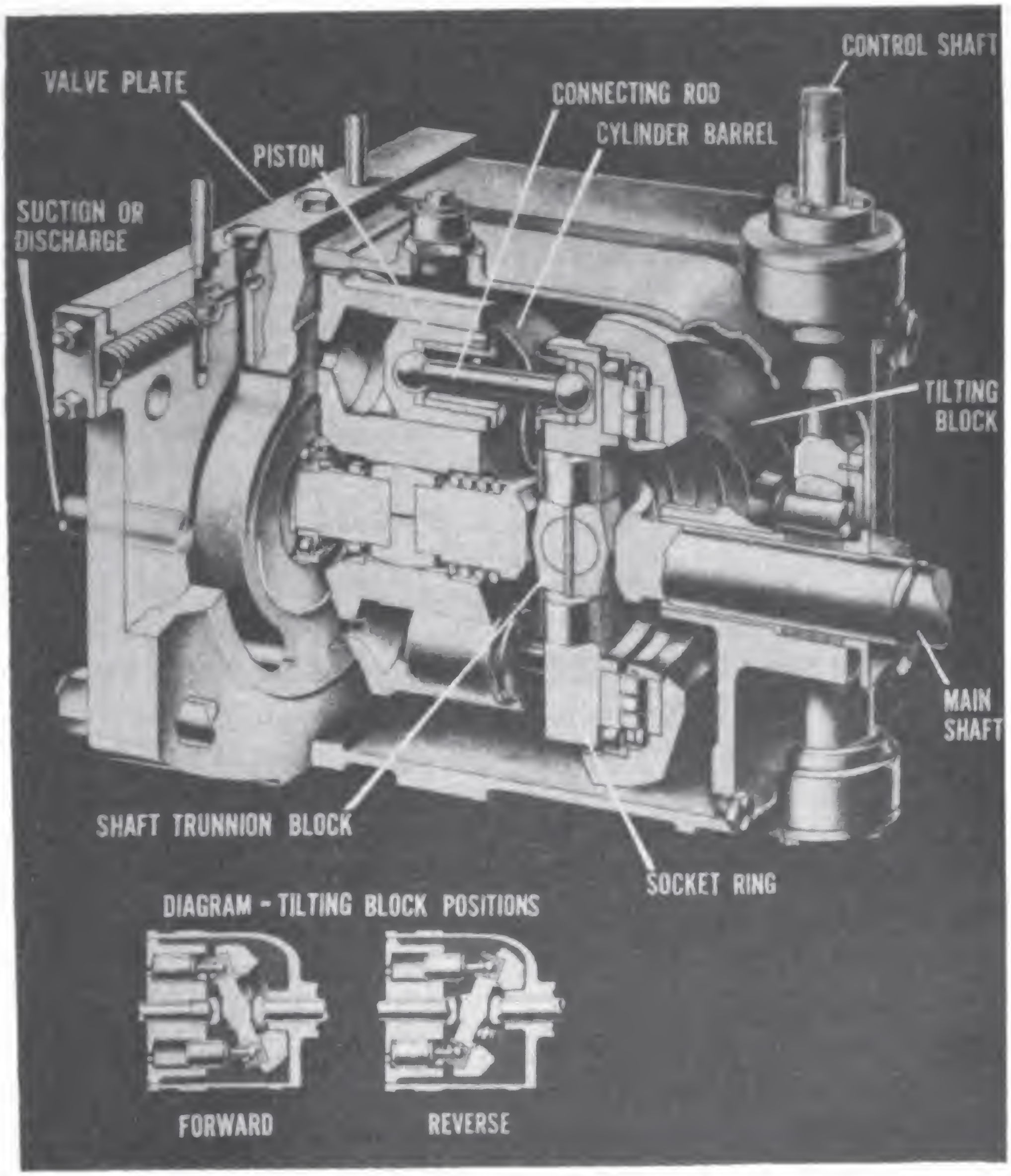


Figure 5-8.—Axial-piston variable stroke pump.

a part of a variable speed gear such as in electrohydraulic anchor windlasses, cranes and winches, and the power transmitting unit in electrohydraulic steering engines, the tilting box is so arranged that it may be tilted in either direction. Thus the pump may be used to transmit power hydraulically to pistons or rams, or it may be used to drive a hydraulic motor. In the latter case, the pump, which is driven by a constant speed electric motor, is called the "A" end of the variable

speed gear and the hydraulic motor is called the "B" end.

The "B" end unit of the hydraulic speed gear is exactly the same as the "A" end of the variable stroke pump described above, except that it does not have a variable stroke feature. The tilting box is installed at a permanently fixed angle. Thus, the "B" end becomes a fixed stroke axial piston pump.

The hydraulic motor or "B" end is directly connected hydraulically to the pump, so that both the pump and the motor use the same valve plate. In some installations the motor is set up at a distance from the pump, and the two units are connected by piping.

Hydraulic fluid introduced under pressure to a cylinder causes the piston to be pushed out. In being pushed out, the piston, through its connecting rod, will seek the point of greatest distance between the cylinder barrel and the socket ring. The resultant pressure of the piston against the socket ring will cause the cylinder barrel and the socket ring to rotate. This action occurs during the half revolution while the piston is passing the intake port of the motor, which is connected to the pressure port of the pump. After the piston of the motor has taken all the hydraulic fluid it can from the pump, the piston passes the valve plate land and starts to discharge the oil through the outlet ports of the motor to the suction inlet of the pump, and thence to the suction pistons of the pump. The pump is constantly putting pressure on one side of the motor while it is constantly receiving hydraulic fluid from the other side. The fluid is merely circulated from the pump to the motor, and back again.

The pumping action of the RADIAL-PISTON VARIABLE STROKE PUMP is similar to the axial-piston type just described. However, the arrangement of component parts is different. In the radial-piston pump, the cylinders are arranged radially in a cylinder body which rotates around a nonrotating central cylindrical valve.

Each cylinder communicates with horizontal ports in the central cylindrical valve. Plungers or pistons, which extend outward from each cylinder, are pinned at their outer ends to slippers which slide around the inside of a rotating floating ring or housing.

The floating ring is so constructed that it can be shifted off center from the pump shaft. When it is in the neutral position, the pistons do not reciprocate and the pump does not operate, even though the electric motor is still causing the pump to rotate. If the floating ring is forced off center to one side, the pistons reciprocate and the pump operates. If the floating ring is forced off center to the other side of the pump shaft, the pump also operates but the direction of flow and the amount of flow are both determined by the position of the cylinder body relative to the position of the floating ring.

ROTARY PUMPS

The operation of a positive-displacement or rotary pump depends upon the principle that rotating screws, lobes, or gears trap the liquid in the suction side of the pump casing and force it to the discharge side. Positive-displacement pumps have largely replaced reciprocating pumps for pumping viscous liquids in naval vessels, as they have a greater capacity per weight and occupy less space. (Positive displacement means that a definite quantity of liquid is pushed out on each revolution.)

Rotary pumps are designed with very small clearances between rotating parts, and between rotating and stationary parts, in order to minimize slippage (leakage) from the discharge side back to the suction side. With close clearances, it is necessary to operate these pumps at relatively low speeds in order to obtain reliable operation and maintain capacity over an extended period of time. (Some rotary pumps operate at 1750 rpm or higher.) Operating the pumps at higher speeds would

cause erosion and excessive wear, which would result in increased clearances.

Types of Rotary Pumps

There are several types of positive displacement rotary pumps, including the simple-gear type, herringbone-gear type, helical-gear type, lobe type, and screw type (low pitch and high pitch). The main features of gear and screw pumps will be discussed briefly in the following paragraphs.

The SIMPLE GEAR PUMP has two spur gears which mesh together; one is the DRIVING GEAR, and the other is the DRIVEN GEAR. Clearances between the gear teeth and the casing and between the gear faces and the casing are only a few thousandths of an inch. Figure 5–9 illustrates the operating principles of the simple gear pump. When the gears turn, liquid in the spaces between the teeth, at the suction side of the pump, is carried by the teeth towards the sides. Then the liquid is trapped between the tooth pockets and the casing, and carried through to the

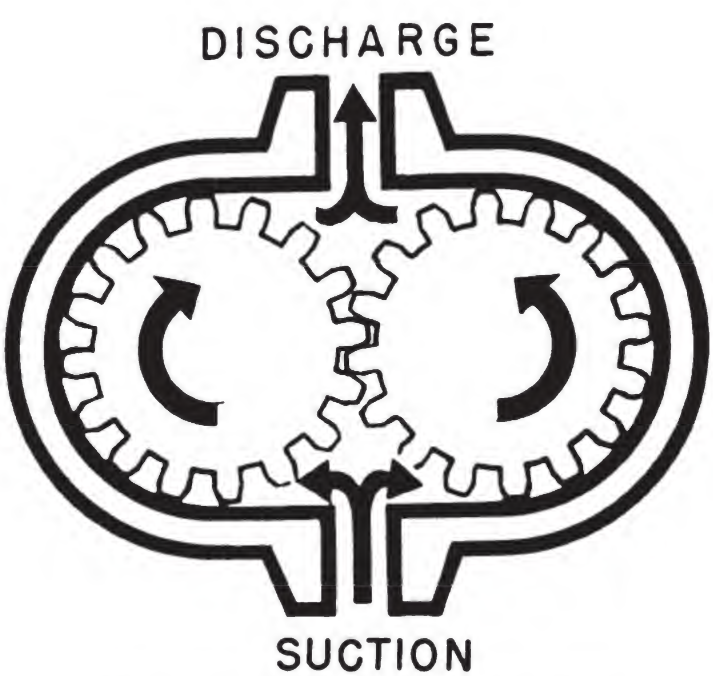


Figure 5–9.—Action of simple gear pump.

discharge side of the pump. The liquid entering the discharge side cannot return to the suction side because the meshing teeth at the center force the liquid out of the tooth pockets. (The small lubricating oil pumps installed on many pumps and other auxiliary machinery are usually positive displacement rotary pumps of the simple gear type.)

The HERRINGBONE GEAR PUMP is a modification of the simple gear pump. In the herringbone gear pump, one discharge phase begins before the previous discharge phase is entirely complete. This overlapping tends to provide a steadier discharge pressure than is obtained with the simple gear pump. In addition, the power transmission from the driving gear to the driven gear is smoother. There are no driving gears other than the pumping gears themselves. Power-driven pumps of this type are sometimes used for low-pressure fuel oil service, lubricating oil service, and Diesel oil service. Figure 5–10 illustrates a sectional view of a herringbone gear pump.

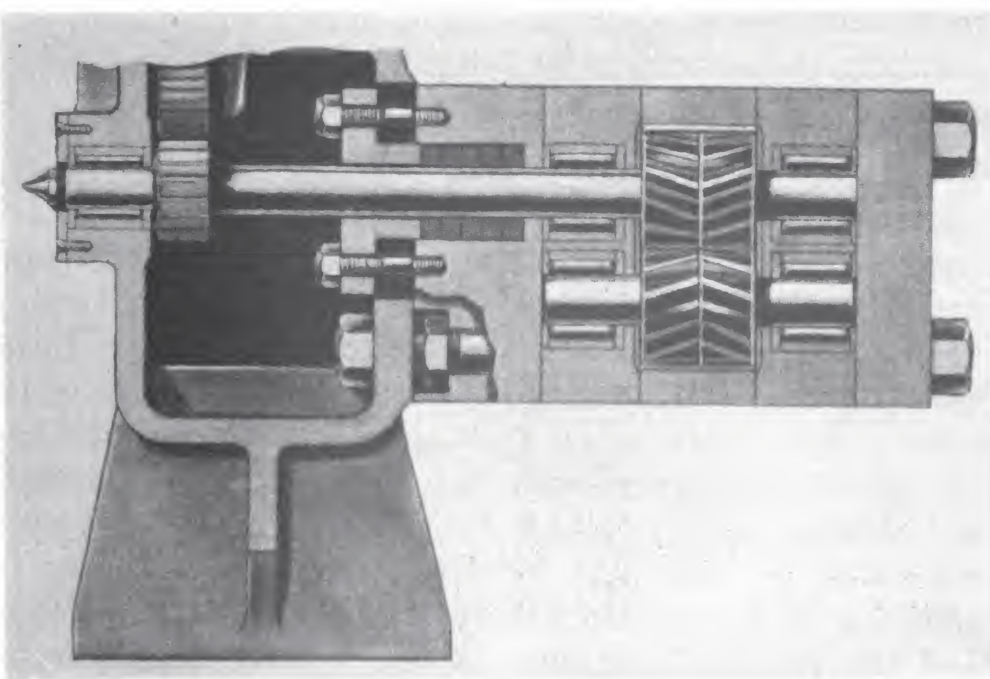


Figure 5–10.—Sectional view of herringbone gear pump.

The HELICAL GEAR PUMP is still another modification of the simple gear pump. Because of the helical gear design, the overlapping of successive discharges from spaces between the teeth is even greater than it is in the herringbone gear pump; and the discharge flow is, accordingly, even smoother. Since the discharge flow is smooth in the helical gear pump, the gears can be designed with a small number of teeth—thus allowing increased capacity without sacrificing smoothness of flow.

In this type of pump, the pumping gears are driven by a set of timing and driving gears, which also function to maintain the required close clearances while preventing actual metallic contact between the pumping gears. (Metallic contact between the teeth of the pumping gears would provide a tighter seal against slippage; however, it would cause rapid wear of the teeth because foreign matter in the pumped liquid would be present on the contact surfaces.) Roller bearings at both ends of the gear shafts maintain proper alignment and decrease friction loss in the power transmission. Stuffing boxes are used to prevent leakage at the shafts. This pump is used to move nonviscous liquids and light oils at high speed. In addition, it can be used to pump heavy, viscous materials at lower speed.

The LOBE-TYPE PUMP is still another variation of the simple gear pump. (Modified versions of lobe pumps are used as superchargers on some engines and on vapor compression distilling plants.) The lobes are considerably larger than gear teeth, but there are only two or three lobes on each rotor. The rotors are driven by external spur gears on the rotor shafts. Some lobe pumps are fitted with replaceable inserts (gibs) at the extremities of the lobes. These gibs take up the wear which would otherwise be sustained by the ends of the lobes. In addition, they maintain a tight seal between the lobe ends and the casing. The inserts are usually seated on a spring, and are therefore able to automatically compen-

sate for considerable wear of both the gibs and the casing. Replaceable cover (liner) plates are fitted at each end of the casing, where the lobe faces cause heavy wear.

SCREW-TYPE PUMPS exist in many variations of design. The three primary differences between these variations are the number of intermeshing screws, the pitch of the screw (low or high pitch), and the general direction of fluid flow (single or double flow).

The LOW-PITCH, DOUBLE-SCREW pump is illustrated in figure 5–11. The two pairs of screws which intermesh with close clearances are mounted on two parallel shafts. Each pair of screws is oppositely threaded with respect

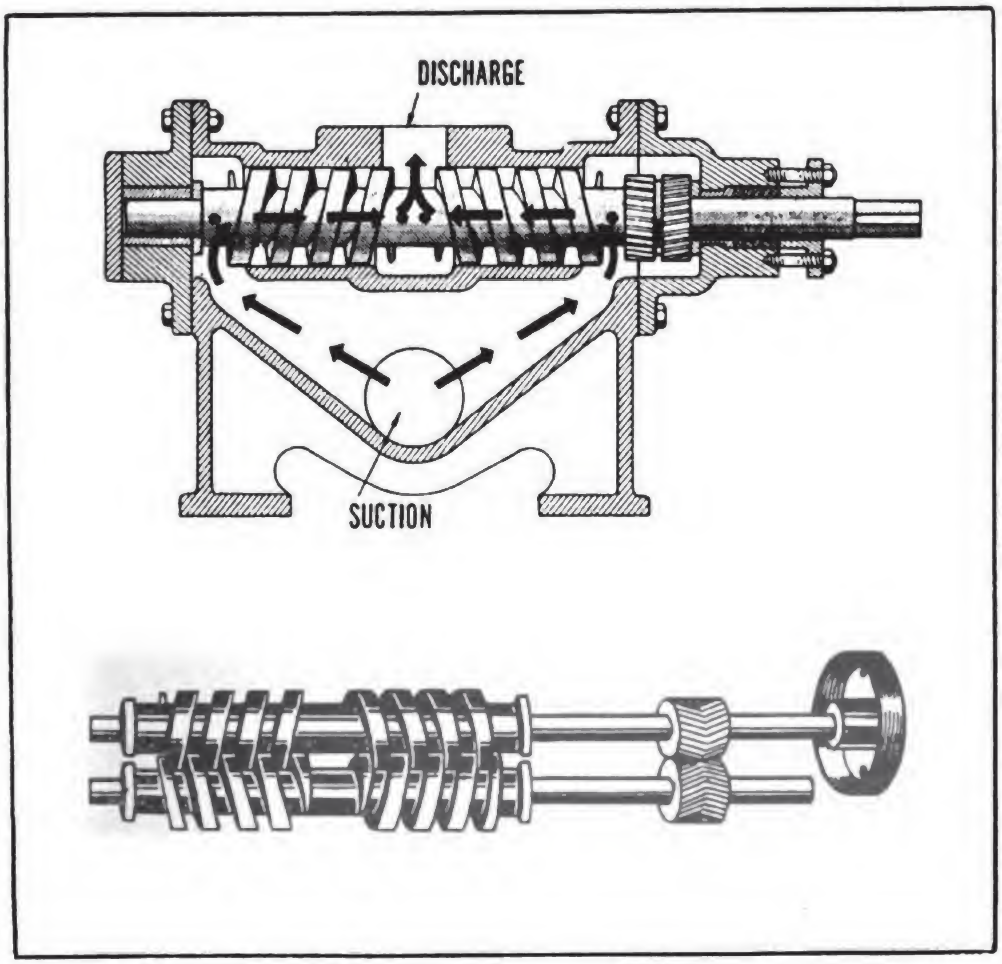


Figure 5–11.—Low-pitch double-screw pump.

to the other pair. One shaft drives the other through a set of herringbone timing gears which maintain clearances between the screws as they rotate.

All clearances are small; however, there is no actual contact between the screws, or between the screws and the casing. The liquid is trapped between the grooves of the screws and the casing, as indicated in the illustration. The meshing of the threads of the two screws

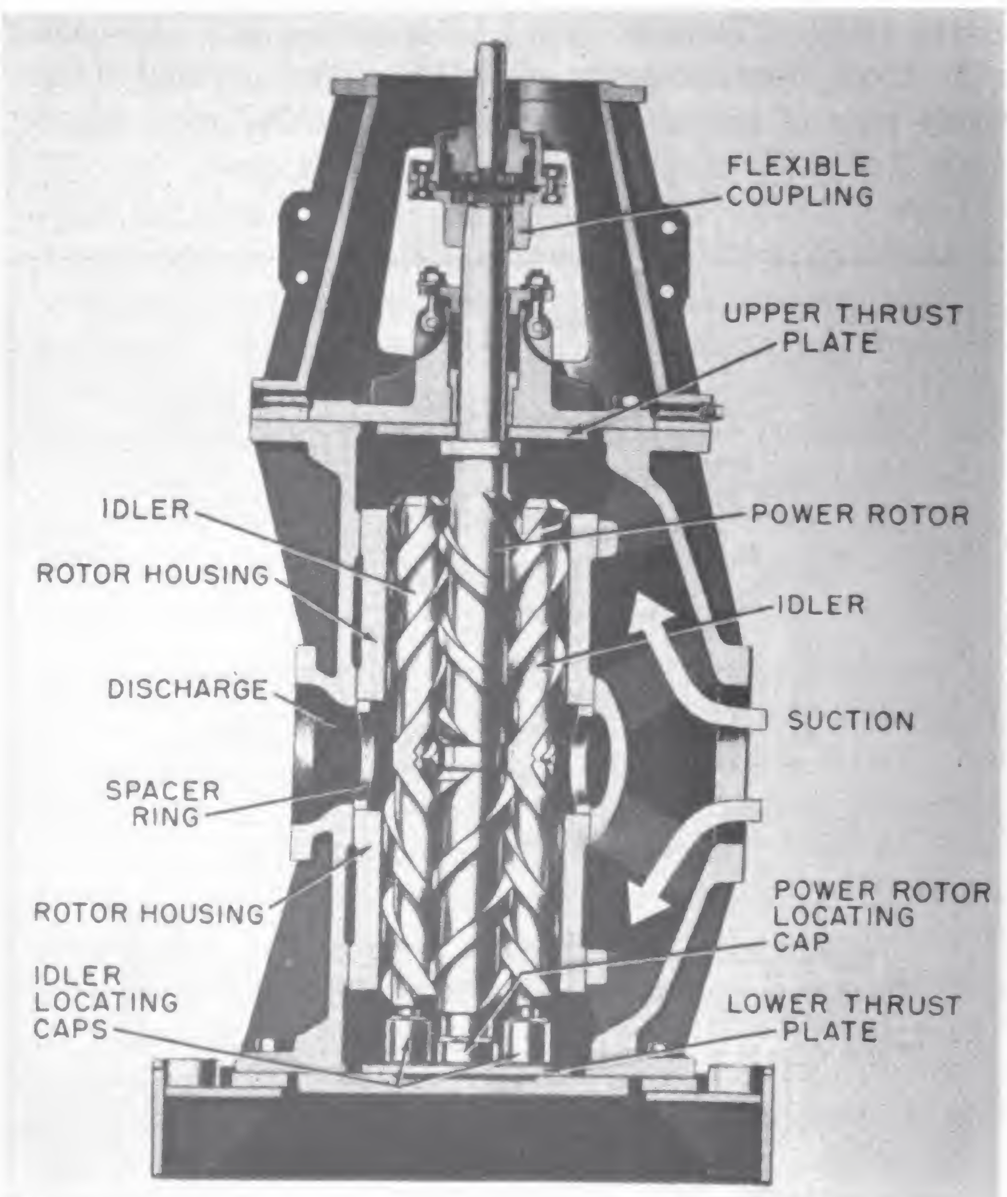


Figure 5–12.—Cutaway view of triple-screw high-pitch pump.

chases the liquid along the grooves, toward the center, or discharge side of the pump. In the pump illustrated in figure 5–11, the liquid enters the thread grooves at both ends of the rotors or screws; thus the axial thrust of each side is balanced.

The operation of a TRIPLE-SCREW (HIGH-PITCH) pump is similar to that of the double-screw low-pitch pump. Figures 5–12 and 5–13 illustrate a TRIPLE-SCREW HIGH-PITCH PUMP. The pitch of the screws is much longer than in the low-pitch screw pump. This enables the cen-

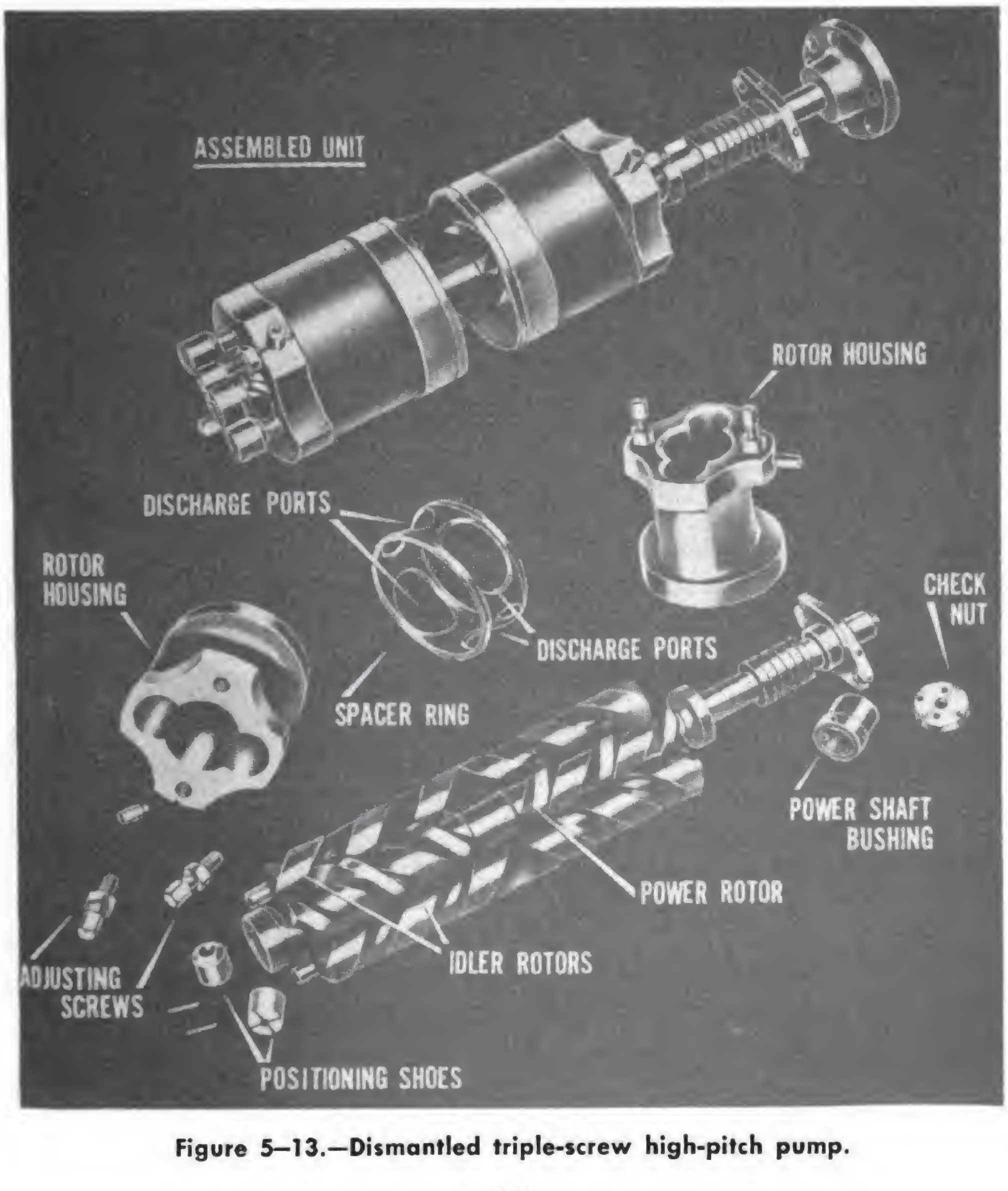


Figure 5–13.—Dismantled triple-screw high-pitch pump.

ter screw, or power rotor to be used to drive the two outer idler rotors directly, without external timing gears. The diameters of the idlers are less than that of the power rotor.

Operating a Rotary Pump

The operating instructions for the driving units of rotary, as well as centrifugal, pumps vary. Therefore, it is best to read the posted instructions, for the individual driving unit and pump, before operating a specific pump. The following instructions, however, are to be observed when STARTING a rotary pump:

1. Check the lubricating oil level in the sump tank or bearing housing. Fill oil cups or reservoir, if fitted. If the rotary pump is lubricated by a detached pump, open and adjust all delivery and return valves.
2. Open the valves on the pump packing gland seals, where such valves are fitted.
3. Lift all relief and sentinel valves by hand.
4. Open the pump discharge valve.
5. Open the pump suction valve.
6. Start the driving unit—motor or engine. (See instructions for operating controllers and motors in chapters 62 and 63 of BuShips *Manual.*)
7. Check the lubricating system to see that all bearings are supplied with oil and that the oil is at the correct pressure.
8. Check all gages to see that proper pressures are being developed.
9. Adjust the pump-shaft packing glands and gland-sealing needle valve where fitted and where adjustment is needed.

The instructions for STOPPING and SECURING a pump are as follows:

1. Close the throttle valve gradually or stop the motor, being sure that the check valve of the pump discharge closes to prevent a back flow, through the pump being secured, from another pump which may be discharging into the same line.
2. Close the pump discharge stop valve.
3. Close the pump suction valve.
4. Close all supply and return valves, when the unit is lubricated by a detached pump or by a main lubricating oil system.

Operating Difficulties

If the pump fails to build up the required pressure, or if it fails to discharge fluid when the discharge valve is open, and the pump speed is increased, proceed as follows:

1. Stop the unit.
2. See that all valves in the pump suction lines are open.
3. Check the packing of all suction and suction manifold valve stems to make certain that no air is being drawn into the suction piping.
4. Check the pump shaft packing for air leakage into the pump.
5. Check the spring case of the discharge relief valve where the relief valve discharges back to the suction pipe; see that no air is leaking into the pump suction.
6. Start the pump again. When it is up to the proper speed, read the suction gage to see if the pump is pulling a vacuum. If a low vacuum (5 or 6 inches of mercury, or less) is indicated, air is leaking into the pump suction. If no vacuum is shown on the suction gage, it is possible that the pump is not primed. (This should rarely occur after the pump casing has once been filled.) If the pump still does not build up pressure, close the discharge valve gradually, and note the pressure gage at the same time. If the pressure increases, an open discharge

line is indicated. If the pressure does not increase, open the discharge valve and close the suction valve, noting if the vacuum builds up. If the pump is in good condition with close clearances, a vacuum ranging from 15 to 25 inches should build up on the suction line. If a high vacuum is indicated, an obstruction in the suction line is probably responsible for failure of the pump to build up discharge pressure; or the suction strainer, if fitted, may be clogged.

If heavy POUNDING of the pump occurs when it is operating at high vacuum, considerable vaporization in the liquid end may be indicated. Pounding can be reduced by decreasing the pump speed.

Care and Maintenance

The instructions given in this chapter for the maintenance, repair, and operation of pumps are general for all makes and types. For all pump installations except some small miscellaneous motor-driven pumps, manufacturers' instruction books are furnished with plans. These instruction books contain detailed information concerning the specific pump installed. These books should be studied carefully before attempting to operate or service an individual pump.

WEARING PLATES AND LINERS.—The clearances between pump rotors and casing wearing plates and cylinder liners should be maintained in accordance with manufacturers' plans. On low-pressure low-suction lift pumps, such as lubricating oil, Diesel oil supply, and tank drain pumps, the pressure drop across the clearance spaces does not generally exceed 50 psi. With these types of pumps, the clearance between parts may wear as much as 0.005 to 0.010 inch without appreciable affect upon the capacity of the individual pump. However, when the clearances are excessive, renewal of parts (wearing plates and liners) will be necessary. If, in the case of fuel oil tank drain pumps, the pump will pull a vacuum of at least 16 inches

mercury, with the suction valve closed, renewal of parts will also be necessary. In each case (where renewal may be required), the engineering officer should decide whether or not the amount of wear or increased clearance necessitates renewal of parts.

If the pump bearings are worn excessively and it becomes necessary to renew the bearings, do not install the new bearings without spotting them in, or checking and fitting them to the designed clearance. (A description of how to fit bearings is given in the section dealing with centrifugal pumps.) The required oil clearance for bearings is usually given on the manufacturers' plans. If these plans are not available, refer to the table of tolerances and clearances in chapter 40 of BuShips *Manual.*

TIMING GEARS.—Pumps fitted with timing gears must have the correct clearance between the two pumping rotors during operation. To accomplish this, the gears must be securely locked to the rotor shafts in their exact designed position. Be sure that there is no lost motion caused by the looseness of keys or pins holding the rotors in the shafts.

THRUST BEARINGS.—The importance of the proper setting of thrust bearings, which hold the pumping elements centrally in the pump casing, cannot be overstressed. Thrust bearings should be examined quarterly and the position of the rotors checked. When the rotor position is being checked, sufficient allowance should be made for expansion of the shaft from the cold condition to the hot running condition.

COUPLINGS.—When the driving unit is connected to the pump by means of a flexible coupling, remember that the coupling is intended to take care of but slight misalignment. Where misalignment is small, the coupling should operate satisfactorily without requiring frequent renewal of parts (coupling). However, if misalignment is excessive, the coupling parts are subjected to severe punishment, necessitating frequent renewal of pins, bushings, and bearings.

Couplings with self-contained oil have been used for a number of years and, if kept lubricated, proved satisfactory. However, some couplings may become defective because oil has been lost, or no oil has been added, resulting in wear and breakage of teeth. Therefore, the following precautions should be observed:

1. Inspect the flexible coupling monthly by removing the filler plug to make sure that there is a sufficient supply of lubricant.
2. Whenever a coupling is dismantled, inspect the teeth to see that they are in good condition. When the coupling is reassembled, check the alignment of the turbine and pump in order to prevent excessive coupling wear.

PUMP LUBRICATION.—Lack of proper lubrication is the primary cause of all pump failures. Reciprocating engine-driven pumps are usually lubricated by either sight-feed drip cups or wick lubrication. See that oil cups are filled with oil and that an adequate supply is being fed to the bearings.

Motor-driven pumps and some Diesel engine-driven pumps fitted with ball bearings are usually fitted for grease lubrication. Before starting, see that all grease cups and bearing housings are filled with lubricant and that no water or foreign matter is in the bearing housing. Grease lubrication is used for the twofold purpose of lubricating the bearing and excluding water and foreign matter from the bearing housing. Water pump shafts are usually fitted with water flingers between the pump shaft stuffing-box gland and the bearing housing. See that such flingers prevent the entrance of water, from the pump glands, to the bearing housing. Occasionally you will find that sleeves fitted on pump shafts do not fit the shaft tightly and water can leak under the shaft sleeves. If such leakage exists, care should be taken to prevent water from entering the bearing housing.

Tests and Inspections

The following tests and inspections should be made on rotary pumps, and the results entered in the appropriate check-off list or log:

1. DAILY. Turn idle pumps by hand.
2. WEEKLY. Check the operation of the discharge check valves (if installed). Check the condition of the lube oil; in particular, check for the presence of water in the lube oil.
3. QUARTERLY. Test all relief valves by water, or oil, as appropriate. Check the thrust bearings and the position of the pump rotors. Check the bearing clearance by leads or bridge gage readings. Check all foundation bolts and dowel pins. If the pump fails to produce the required vacuum, it should be opened and repaired as necessary. Clean the lube oil system and renew oil and grease.
4. ANNUALLY. Open the pump and reduction gear casings for inspection and cleaning. Measure the clearances of all wearing plates and liners, casing throat bushing, rotors, casing liners, bushings, and renew parts if necessary. Examine all rotors, shafts, bearings, timing gears, and reduction gears.

Safety Precautions

The following precautions must be observed in the operation of rotary pumps:

1. See that all relief valves are tested at the appropriate intervals. Make certain that relief valves function at the designated pressures.
2. Never attempt to jack over a pump by hand while the power is on.
3. Never operate a positive displacement rotary pump with the discharge valve closed, unless the discharge is protected by a properly set and tested relief valve.

CENTRIFUGAL PUMPS

Aboard ship, centrifugal pumps are used for main circulating, condensate, fire, gasoline, cargo, and many other applications. Most modern Diesel and gasoline engines employ centrifugal pumps for circulating both fresh and sea water. (These pumps are generally known as water pumps.) There are many types of centrifugal pumps, but all operate on the same principle. The operation of centrifugal pumps depends upon a force (centrifugal) which imparts a high velocity to the liquid pumped. This force is produced by the rotation of the impeller at high speed. The liquid is sucked in at the center or EYE of the impeller and discharged at the outer rim of the impeller.

By the time the liquid leaves the impeller, it has acquired a high velocity and kinetic energy. The liquid is slowed down by being led through a volute or through diffusion vanes. As the velocity of the liquid decreases, its pressure increases; in this way the kinetic energy of the liquid is changed to potential energy.

Types of Centrifugal Pumps

There are two types of centrifugal pumps which you will probably encounter aboard ship: the volute pump and the volute turbine pump.

In the VOLUTE PUMP, shown in figure 5–14, the impeller

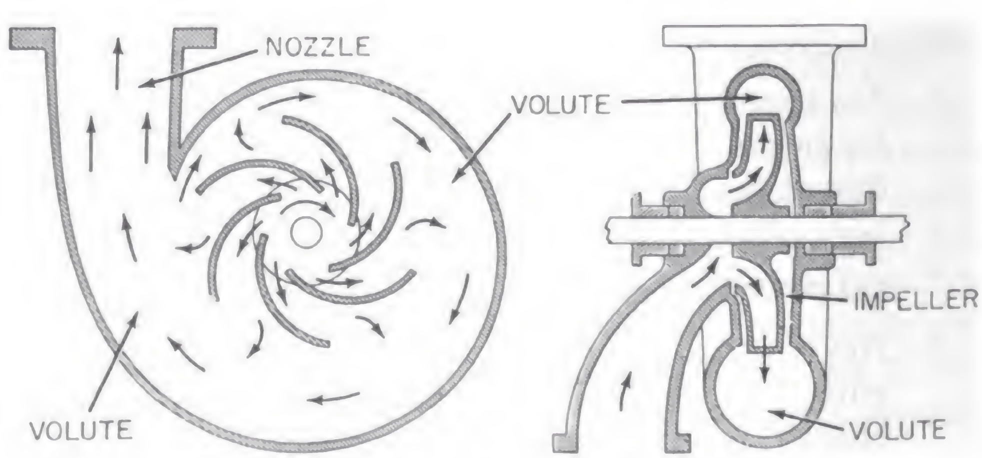


Figure 5–14.—Simple volute pump.

discharges into a volute—that is, a gradually widening channel in the pump casing. As the liquid passes through the volute and into the discharge nozzle, a considerable portion of its kinetic energy is converted into potential energy.

In the VOLUTE TURBINE PUMP, shown in figure 5–15, the liquid leaving the impeller is first slowed down by the stationary vanes which surround the impeller. The liquid is forced through the gradually expanding passages of the diffuser ring before entering the volute. Since both the diffuser vanes and the volute reduce the velocity of the liquid in the volute turbine pump, practically all the kinetic energy is converted to potential energy.

Centrifugal pumps may be classified in several ways. For example, they may be either SINGLE-STAGE or MULTI-STAGE. A single-stage pump has only one impeller. A multistage pump has several impellers housed together in one casing; each impeller functions separately, discharging to the suction of the next stage impeller. Centrifugal

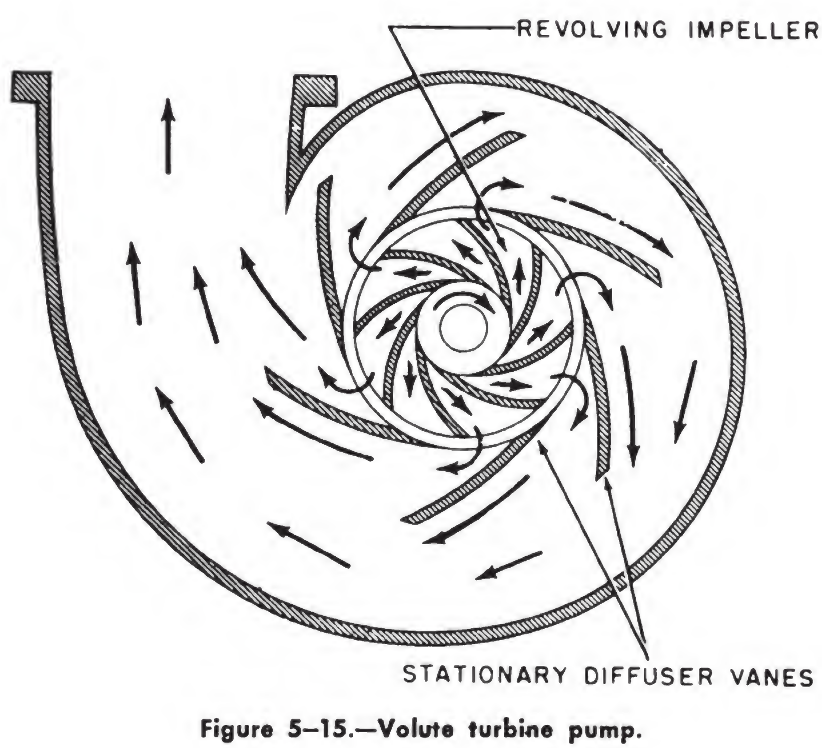


Figure 5–15.—Volute turbine pump.

pumps are also classified as HORIZONTAL or VERTICAL, depending upon the position of the pump shaft.

The impellers used on centrifugal pumps may be classified as SINGLE-SUCTION or DOUBLE-SUCTION. The single-suction impeller allows liquid to enter the eye from one direction only; the double-suction type allows liquid to enter the eye from two directions. Impellers are also classified as CLOSED or OPEN. Closed impellers have side walls which extend from the eye to the outer edge of the vane tips; open impellers do not have these side walls. Most centrifugal pumps used by the Navy have closed impellers.

Construction of Centrifugal Pumps

The LIQUID END of a centrifugal pump has a casing made up of two castings flanged together, so that the top half can be removed for inspection and repair of the pump. The shaft is protected from excessive wear and corrosion by bronze and corrosion-resisting-steel sleeves wherever the shaft comes in contact with the liquid being pumped, or with the shaft packing.

The IMPELLERS are carefully machined and balanced to reduce vibration and wear, since they rotate at very high speed. A close radial clearance must be maintained between the outer hub of the impeller and that part of the pump casing in which the hub rotates, in order to minimize leakage from the discharge side of the pump casing to the suction side. (In order to prevent corrosion of pumps that handle sea water, the impellers and casings of these pumps are made of bronze or gun metal, and the shaft of monel metal or stainless steel.)

Because of the high rotational speed of the impeller and the close clearance, the running surfaces of both the impeller hub and the casing at that point are subject to relatively rapid wear. In order to eliminate the need for renewing an entire impeller and pump casing because of wear, centrifugal pumps are provided with replaceable wearing rings. One ring is attached to each outer hub of

the impeller, and rotates with the impeller. This ring is called the IMPELLER WEARING RING. The other ring, which is stationary and attached to the casing, is called the CASING WEARING RING. Figure 5–16 illustrates the impeller and wearing rings.

It should be noted that some small pumps with single-suction impellers are made with a casing wearing ring only, and no impeller ring; in this type of pump, the casing wearing ring is fitted into the end plate.

In many centrifugal pumps, the shaft is fitted with replaceable sleeves. The advantage of using sleeves is that they can be replaced more economically than the entire shaft.

RECIRCULATING LINES are installed on centrifugal pumps to prevent the pumps from overheating and becoming vapor bound, in case the discharge is entirely shut off. Seal piping is also installed to cool the shaft and the packing, to lubricate the packing, and to seal the joint between the shaft and the packing against air leakage.

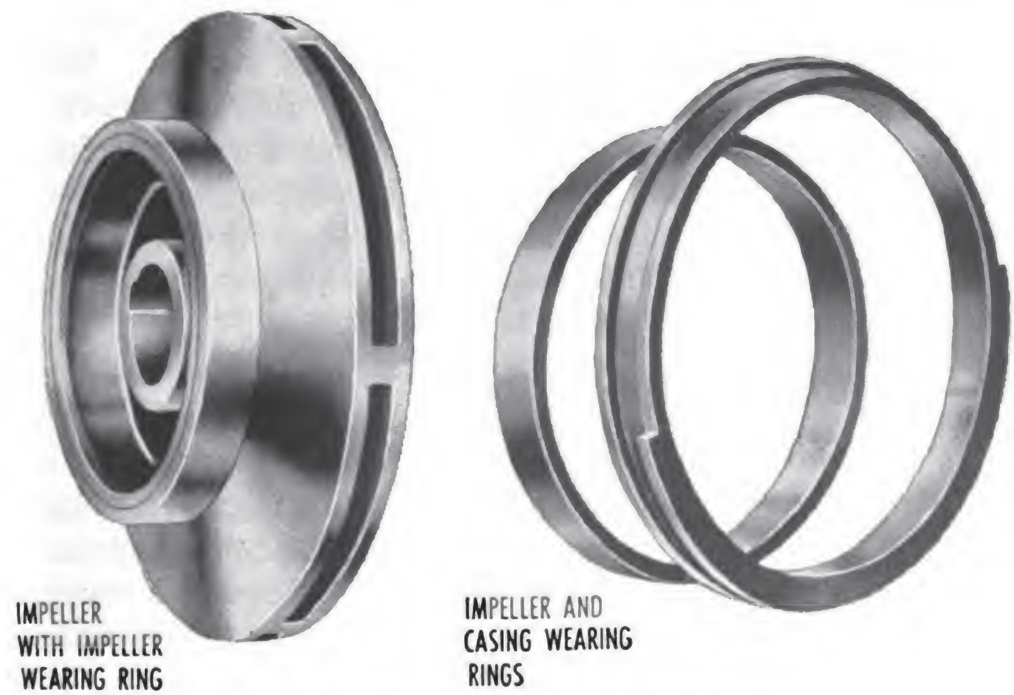


Figure 5–16.—Impeller and wearing rings.

A lantern ring spacer is inserted between the rings of the packing in the stuffing box. Seal piping leads the liquid from the discharge side of the pump to the annular space formed by the lantern ring. The web of the ring is perforated so that the water can flow in either direction along the shaft, between the shaft and the packing.

SHAFT and THRUST BEARINGS support the weight of the impeller and maintain the position of the rotor, both radially and axially. (Radial bearings may be of the sleeve or ball type. Thrust bearings may be of the ball type or pivoted segmental type.)

The POWER END of a centrifugal pump may be driven by a steam turbine, by an electric motor, or by a Diesel engine. Pumps used for continuous service are either turbine or motor driven. (Smaller pumps, such as those used for inport or cruising operation, are, generally, motor driven.) Pumps used for emergency firemain services are Diesel driven.

Care and Maintenance of Centrifugal Pumps

The tests, safety precautions, and maintenance factors for rotary pumps, outlined earlier in the chapter, are applicable in a general way to centrifugal pumps. However, some of the information which you must have in order to give proper care and maintenance to centrifugal pumps is given in this section. For additional information, as well as for specific information on any one pump, you should consult BuShips *Manual* and the appropriate manufacturers' instruction book.

LUBRICATION is essential for the proper operation of centrifugal pumps, and inadequate lubrication is a primary cause of pump failure. The supply of oil to the bearings must be checked frequently during each watch. Grease cups and bearing housings must be checked occasionally to ensure that they are free of water and foreign matter. At the same time, check to see that bearings are properly locked on the shafts. Grease should be replenished as often as necessary. When refilling a bearing

housing with grease, remove the pipe opposite the grease gun fitting, and force out the old grease. If you find water in the bearing housing, it should be traced to its source (usually leakage from pump packing), and effective means taken to stop the leakage.

Lubricating oil should be renewed whenever it becomes emulsified or foams excessively, or when it contains sludge, dirt, or other foreign matter.

Lubrication of the pump packing is extremely important. The quickest way to wear out the packing is to forget to open the water piping to the seals or stuffing boxes. If the packing is allowed to dry out, it will score the shaft. When you are operating a centrifugal pump, be sure that there is always a slight trickle of water coming out of the stuffing box or seal.

STUFFING BOX PACKING.—Packing around the shafts of centrifugal pumps may be either of the stuffing box type, or of the labyrinth type, or both. Stuffing box packing should be renewed about every 2 months. The packing should be installed so as to give a uniform thickness all around the shaft sleeves. When installing new packing, pack the stuffing box loosely and set up lightly on the packing gland. Then, with the pump in operation, the gland should be tightened in small steps, with several hours between tightenings, to compress the packing gradually. This procedure will prevent excessive heating and scoring of the shaft or shaft sleeves. A flow of from 40 to 60 drops per minute out of a normal packed type stuffing box is required to provide lubrication and to dissipate generated heat.

After the packing has been compressed, it will usually be found necessary to add more packing. Labyrinth packing around bushings that are worn, due to wearing of the bearings, should be renewed when the bearings are rebabbitted. The water supply to the packing seals should be examined frequently during each watch to ensure that they are clear.

LANTERN RINGS, SLEEVES AND FLINGERS.—When a stuffing box is fitted with a lantern ring, be sure to replace the packing beyond the lantern ring at the bottom of the stuffing box. In addition, see that the sealing water to the lantern ring is not blanked off by the packing.

SLEEVES fitted at the packing on the pump shafts must always be tight. These sleeves are usually made secure by shrinking or keying them to the shaft. Care must be taken to see that water does not leak between the shaft and shaft sleeves. If the shaft or sleeves in the way of packing are roughened or grooved, they should be turned or ground to give a smooth surface. If the surface is very rough, the sleeves should be renewed.

WATER FLINGERS are fitted on shafts outboard of stuffing box glands, to prevent water from following along the shaft and entering the bearing housings. The flingers must be tightly fitted. If the flingers are fitted on the shaft sleeves, rather than on the shaft, make sure that no water is allowed to leak under the sleeves. If leakage does occur, a fiber washer should be fitted between the end of the sleeves and the shaft shoulder, and all clearances between shaft and sleeve should be filled with tallow.

WEARING RINGS, IMPELLER, AND CASING.—The clearances between the impeller and the casing wearings, as shown on manufacturers' plans, should be maintained. When clearances exceed the specified figures, the wearing rings must be replaced. This job can be accomplished by ship's force, but it requires the complete disassembly of the pump. If it is necessary for you to undertake this job, follow the manufacturers' instructions carefully. Improper fitting of the rings or incorrect reassembly of the pump can result in serious damage.

SHAFT ALIGNMENT.—If the shafts are not aligned properly, the unit must be realigned in order to prevent shaft breakage and damage to bearings, pump casing wearing rings, and throat bushings. Shaft alignment should be checked with all piping in place and all tanks and piping filled; and some allowance must be made for

the change in position of parts from cold-check conditions to hot-operating conditions.

BEARINGS.—In a centrifugal pump installation, fitted with an internal water-lubricated bearing inside the pump casing (such as condensate pumps), an adequate supply of clean water, for lubricating and cooling, must be supplied to the bearing. Several types of materials which have been used for internal water-lubricated bearings are as follows:

1. Laminated phenolic material grade FBM (Fabric base bakelite or micarta)
2. High lead content bronze
3. Graphited bronze
4. Lignum vitae bearings are also satisfactory. However, due to greater difficulty of installation, its use is NOT recommended, except in an emergency.

The condition of all types of internal water-lubricated bearings should be checked frequently to guard against excessive wear which results in misalignment and possibly shaft failure.

As far as oil-lubricated shell-type bearings are concerned, the bearing clearances should be measured with leads or by taking bridge-gage readings (where bridge gages are furnished) at least every 6 months. Maintain the clearances, within the limits shown on the manufacturers' plans. If such plans are not available, follow the instructions outlined in chapter 40, table B–4, of BuShips *Manual*.

When measuring the clearance of a bearing by taking leads, the following procedure is used:

1. Remove the upper half of the bearing.
2. Lay several lengths of soft lead wire circumferentially on the journal. Do not use hard fuse wire.
3. Replace the upper half of the bearing and set up on all bearing nuts. Mark the position of each one.
4. Remove the top half of the bearing, examine, and measure the thickness of the leads, with a micrometer.

The best method of placing the leads on the journal is shown in figure 5–17. Leads should not be used which are heavier than required for the clearance to be measured. When taking leads, see that all bolts, bolt holes, bearing surfaces, liners (if used), and butting faces of the shells are free from foreign matter. When the leads have been properly placed and the bearing assembled, the nuts should be run down to bring the shells solidly against the liners, if used, or the metal to metal of butting faces. (Do not apply an additional force to the nuts because it may result in deforming the threads or straining the metal of the bolts.) When set up, the position of the bearing nuts should be marked so that they may be again tightened the same amount after the leads have been removed.

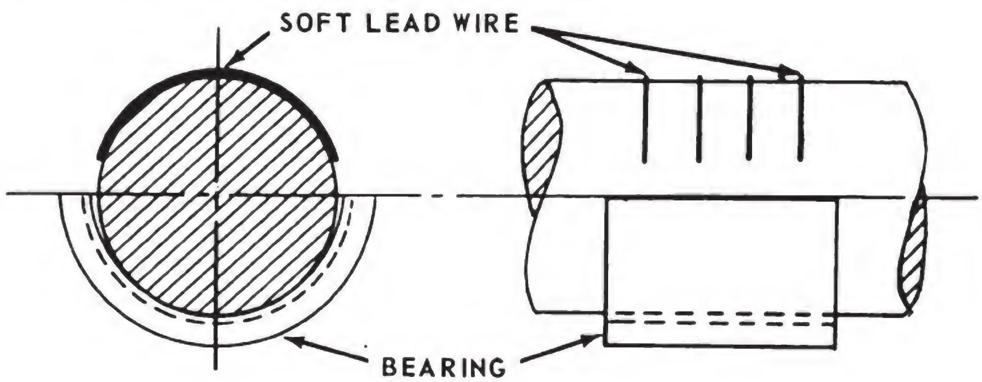


Figure 5–17.—Taking leads.

When the leads are removed from the journal, one end of each lead should be pinned to a piece of paper. The leads should be spaced the same distance apart and arranged in the same order as they were on the journal. If the lead is found to be squeezed out evenly along its entire length, the clearance is uniform. To determine the bearing clearance, measure each lead at, or near, its midpoint. The average thickness will indicate the bearing clearance, provided there is no great variation in the thickness of the individual leads. In addition, the thickness of each lead should be carefully measured at several places, with a micrometer, along the length of the wire.

Leads which vary in thickness indicate an uneven bearing surface. Such bearings should be refitted to give uniform clearance.

To fit a bearing to its journal, coat the journal with thin, red lead and oil, or black lead and oil, or prussian blue. Lay one of the bearing halves on the journal and rotate it back and forth slightly. Remove the bearing half and examine the surfaces for high spots. The high spots are located in the area where the coloring compound has adhered to the bearing surface. These spots must be scraped. Continue to produce a smooth and even contact surface until the spots are uniformly distributed over the bearing surface, and cover such an area as to indicate that practically all of the surface is in contact with the journal. To ensure proper fitting of the bearing, repeat the above operations with the bearing in its proper position on the journal, and with the bolts in place and properly set up. With large bearings or with bearings that are not easily accessible, use a mandrel the exact size of the journal. During the finishing operations, you should, as a final check, spot the bearing to the journal. After the bearing has been spotted in, take leads to determine if the bearing clearance is satisfactory. When the clearance is satisfactory, record the final clearance in the Machinery History.

In scraping in a bearing, care must be taken that the lining is concentric with the shell. (If the concentricity of a bearing is lost, the pump shaft may become misaligned. This will not only cause unequal loads on the bearings along the shaft but is also likely to destroy the clearances between the casing wearing rings and the impeller wearing rings.)

With very small bearings the amount of clearance is often determined by "feel." These bearings should be fitted as previously described and assembled on their journals with the bearing nuts set up hard. If the clearance is correct, there will be only the slightest indication

of play between the bearing and its journal, and the journal will revolve easily.

Major Troubles and Repairs

A list of the principal troubles that may occur with centrifugal pumps, together with their causes, is given below. In the majority of cases, the trouble is external to the pump, and these causes should be carefully investigated before undertaking repairs:

1. FAILURE TO DELIVER WATER
   a. Pump not primed
   b. Insufficient speed
   c. Impeller plugged
   d. Wrong direction of rotation (this may occur after motor overhaul)
2. SHORT IN CAPACITY
   a. Air leaks in stuffing boxes
   b. Insufficient speed
   c. Insufficient suction head for hot water
   d. Suction strainers fouled
   e. Impeller partially clogged
   f. Mechanical defects; wearing rings worn; impellers damaged and casing packing defective.
3. PRESSURE LOW
   a. Insufficient speed
   b. Air leaks
   c. Incorrect discharge valves open in manifold (this may allow the pump to discharge into an open line, causing the pump to operate at other than the design point)
   d. Mechanical defects, same as 2, f, above
4. PUMP LOSES WATER AFTER STARTING
   a. Leaky suction line
   b. Water seal plugged
   c. Suction lift too high (often caused by fouling of the strainer after the pump is started)
   d. Air or gases in water

5. Pump overloads driver
    a. Speed too high
    b. Liquid of different specific gravity and viscosity higher than normal
    c. Rubbing caused by foreign matter in the pump, and between the case rings and the impeller
    d. Mechanical defects: rotating element binds; shaft bent; and worn bearings.
6. Pump vibrates
    a. Misalignment
    b. Poor foundation
    c. Impeller partially clogged, causing unbalance
    d. Mechanical defects, same as 5, d, above.

If the pump fails to build up pressure when the discharge valve is opened and the pump speed increased, proceed as follows:

1. Secure the pump.
2. See that the pump is primed and that all air is expelled through the air cocks on the pump casing.
3. See that all valves on the pump suction line are open.
4. Start the pump again. If the discharge pressure is not normal when the pump is up to its proper speed, the suction line may be clogged, or an impeller broken. It is also possible that air is being drawn into the suction line or into the casing. If any of these conditions exist, stop the pump, try to find the source of the trouble, and correct it, if possible.

The parts of a centrifugal pump most frequently requiring repair or replacement are:

1. Casing rings and impeller rings.—Since the purpose of these rings is to keep the internal bypassing of the liquid to a minimum, the clearances should be checked and restored, when worn beyond allowable limits, whenever the pump casing is opened up, and at least once each year.

2. Shaft sleeves.—There is a common tendency of operating personnel to take up too hard on the packing in an attempt to prevent stuffing box leakage. This causes scoring of the shaft sleeves. Whenever the pump is opened, the sleeves should be examined and if not badly scored, they should be smoothed up; if they are badly scored, they should be replaced.

3. Bearings.—Worn sleeve bearings cause the rotor to drop; this, in turn, results in wearing of the casing and impeller rings. Bearings of centrifugal pumps should be rebabbitted in accordance with the table in chapter 40 of BuShips *Manual*, when bridge gage readings or leads indicate that maximum allowable wear has occurred. The oil clearances for bearings can be obtained from the manufacturers' plans or instruction books. If such data are not available, refer to the table of tolerances and clearances in chapter 40 of BuShips *Manual*.

   Whenever a bearing is opened up, it should be inspected carefully for ridges, scores, and wear. See if the bearing lining is firmly anchored to the shell. If the bearing is scored, uneven, considerably worn, or the lining loose, the bearing should be replaced with a spare.

   Journals should be kept free from rust, and even at all times. To remove rust spots, ridges, and sharp edges of scores, the journals should be lapped with an oilstone, or with an oilstone powder.

   If it becomes necessary to rebabbitt a small bearing in an emergency, coat the journal heavily with banana oil and, with the shaft properly centered in the bearing housing, pour the babbitt around the journal. The bearing will break clean from the journal and can then be used with little or no scraping in.

4. BUSHINGS.—Whenever a pump is opened up, bushing clearances should be measured. Bearing wear will probably cause bushing wear, and the bushing should be renewed if the bearings are restored to their original readings.

JET PUMPS

Unlike other pumps, the jet pump has no moving parts. A simple jet pump, illustrated in figure 5–18, consists of a jet supply line, a jet or nozzle, a suction line, a suction chamber, a diffuser, and a discharge line.

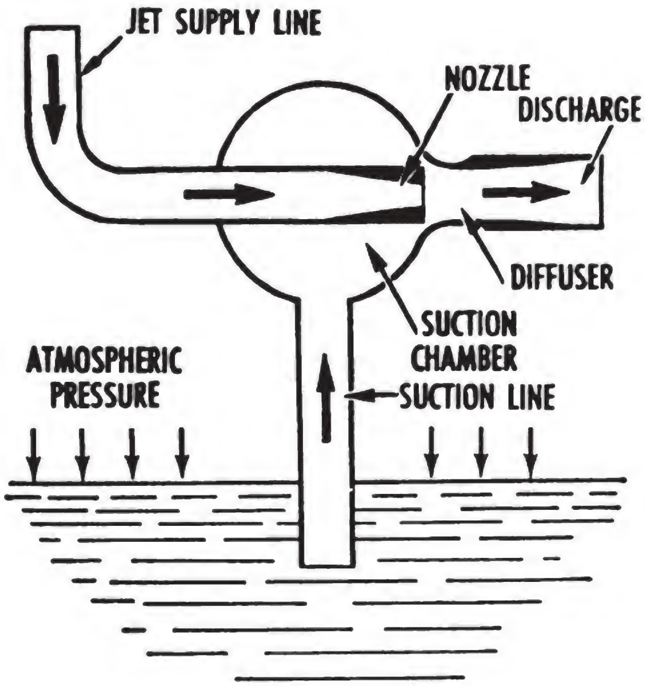


Figure 5–18.—Simple jet-type pump.

In the jet-type pump, pumping action is derived by passing a fluid (water, steam, or air) through a nozzle, at a high pressure and velocity, into as well as through a chamber provided with suction and discharge openings.

The principles of jet pump operation are as follows: Upon starting up, the rapidly moving jet fluid impinges upon, and imparts sufficient motion to the air (or whatever substance may be in the suction chamber) to carry

it out through the discharge line. The displacement of the air from the suction chamber creates a partial vacuum, within the suction chamber, causing fluid to flow into and through the suction line. The fluid entering the chamber from the suction line is acted upon similarly by the high velocity fluid, thus providing continuous pumping action.

The suction lift and discharge pressure of a simple jet-type pump are not so great as the lift and pressure of other types of pumps. However, a special class of jet pumps, such as two-stage air ejectors, is capable of creating greater suction lift than most mechanically operated pumps.

Because of their simplicity, jet pumps generally require very little maintenance. Since there are no moving parts, only the nozzles will show wear. The erosion action will cause the nozzles to become enlarged; in this case they are generally renewed. Occasionally the nozzles are removed, the steam strainers if fitted are cleaned, and a special reamer is inserted in the nozzles to clean out any rust or scale that may have accumulated.

SUMMARY

Since pumps are the most numerous units of auxiliary machinery aboard ship, periodic inspections and maintenance of pumps are very important tasks. As an EN2, you must know the purpose and principles of operation of pumps in the engineroom and in other assigned spaces; particularly reciprocating, gear, and centrifugal pumps.

When maintaining or examining the interior of a pump, make certain that all drawings and important dimensional data are available. Specific instructions for each type pump may be found in pamphlets issued by pump manufacturers.

QUIZ

1. What is the purpose of the piston-type valve gear of a modern reciprocating pump?
2. What is the length of the stroke of a reciprocating pump designated as 8x6x7?
3. What will cause shoulders to be worn in a pump cylinder?
4. How is the length of the stroke adjusted?
5. If a reciprocating pump is frozen, how can you determine if there is excessive friction?
6. If a reciprocating pump has been operating properly and loses pressure on one stroke, what is the probable cause?
7. What may cause groaning in the steam cylinder of a reciprocating pump which has been started after being idle for a long period?
8. Before repairing or examining a pump, what step should be taken?
9. What are the chief causes of a steam or water piston working loose?
10. Before fitting and installing Tuck's flax or other types of soft packing in a pump, what step should be taken, if practicable?
11. Troubles in the steam cylinder result chiefly from what source?
12. In general, what are the results of operating a reciprocating pump which is improperly aligned?
13. What controls the direction of flow in an axial-piston variable stroke pump?
14. In a radial-piston variable stroke pump, what position of the floating ring is necessary before pumping can occur?
15. For pumping viscous liquids, what type pump has largely replaced the reciprocating pump on naval vessels?
16. How are rotary pumps designed to minimize slippage from the discharge side back to the suction side?
17. In a lobe-type pump, what purposes are served by the replaceable inserts (gibs) at the extremities of the lobes?
18. What are the three primary differences between variations in the design of screw type rotary pumps?
19. In starting a rotary pump, the discharge valve is placed in what position?
20. What is the indication of a low vacuum (5 or 6 inches Hg) on the suction side of a rotary pump?
21. What may be indicated by heavy pounding of a rotary pump operating at a high vacuum?

22. How often should thrust bearings on a rotary pump, as well as the position of the rotors, be checked?
23. What two types of centrifugal pumps are used by the Navy?
24. Why are centrifugal pumps provided with replaceable wearing rings?
25. Why are centrifugal pumps provided with recirculating lines?
26. How often is it advisable to renew stuffing box packing of a centrifugal pump?
27. How often should clearances of oil-lubricated shell-type bearings be checked?
28. When measuring the clearance of a bearing by taking leads, what step is first taken?
29. If the suction strainers of a centrifugal pump are fouled and the impeller is partially clogged, what will be the probable effect?
30. If the speed of a centrifugal pump is high and the pump is binding, what is the probable trouble?
31. What centrifugal pump parts require repairs or replacement most frequently?
32. What type of pump has no moving parts?

CHAPTER 6

FUEL INJECTION EQUIPMENT

There are several types of fuel injection systems in use; however, the function of each type is the same. The primary function of a fuel injection system is to deliver fuel to the cylinders at the proper time and in the proper quantity, under various engine loads and speeds.

REQUIREMENTS OF AN INJECTION SYSTEM

In delivering fuel to the cylinders, the fuel injection system must fulfill the following requirements:

1. Meter or measure the correct quantity of fuel injected.
2. Time the fuel injection.
3. Control the rate of fuel injection.
4. Atomize or break up the fuel into fine particles according to the type of combustion chamber.

Metering

Accurate metering or measuring of the fuel means that, for the same fuel control setting, the same quantity of fuel must be delivered to each cylinder for each power stroke of the engine. Only in this way can the engine operate at uniform speed with a uniform power output. Smooth engine operation and an even distribution of the load between the cylinders depend upon the same volume of the fuel being admitted to a particular cylinder each time it fires; and upon equal volumes of fuel being delivered to all cylinders of the engine.

Timing

In addition to measuring the amount of fuel injected, the system must properly time injection to ensure efficient combustion so that maximum energy can be obtained from the fuel. When the fuel is injected too early in the cycle, ignition may be delayed because the temperature of the air at this point is not high enough. An excessive delay, on the other hand, gives rough and noisy operation of the engine, and also permits some fuel to be lost due to the wetting of the cylinder walls and piston head. This, in turn, results in poor fuel economy, high exhaust gas temperature, and smoke in the exhaust. When fuel is injected too late in the cycle, all the fuel will not be burned until the piston has traveled well past top center. When this happens, the engine will not develop its maximum power, the exhaust will be smoky, and the fuel consumption will be high.

Control of Rate of Fuel Injection

A fuel system must also control the rate of injection. The rate at which fuel is injected determines the rate of combustion. The rate of injection at the start should be low enough that excessive fuel does not accumulate in the cylinder during the initial ignition delay (before combustion begins). Injection should proceed at such a rate that the rise in combustion pressure is not excessive, yet the rate of injection must be such that fuel is introduced as rapidly as possible in order to obtain complete combustion. An incorrect rate of injection will affect engine operation in the same way as improper timing. If the rate of injection is too high, the results will be similar to those caused by an excessively early injection; if the rate is too low, the results will be similar to those caused by an excessively late injection.

Atomization of Fuel

As used in connection with fuel injection, atomization means the breaking up of the fuel, as it enters the cylin-

der, into small particles which form a mist-like spray. Atomization of the fuel must meet the requirements of the type of combustion chamber in use. Some chambers require very fine atomization, others can function with coarser atomization. Proper atomization facilitates the starting of the burning process, and ensures that each minute particle of fuel will be surrounded by particles of oxygen with which it can combine.

Atomization is generally obtained when the liquid fuel, under high pressure, passes through the small opening (or openings), in the injector or nozzle. As the fuel enters the combustion space, high velocity is developed because the pressure in the cylinder is lower than the fuel pressure. The created friction, resulting from the fuel passing through the air at high velocity, causes the fuel to break up into small particles.

Distribution of Fuel

A fuel injection system must increase the pressure of the fuel sufficiently to overcome compression pressures and to ensure proper dispersion of the fuel injected into the combustion space. Proper dispersion is essential if the fuel is to mix thoroughly with the air and burn efficiently. While pressure is a prime contributing factor, the dispersion of the fuel is influenced, in part, by atomization and penetration of the fuel. (Penetration is the distance through which the fuel particles are carried by the kinetic energy imparted to them as they leave the injector or nozzle.)

If the atomization process reduces the size of the fuel particles too much they will lack penetration. Lack of sufficient penetration results in the small particles of fuel igniting before they have been properly distributed, or dispersed in the combustion space. Since penetration and atomization tend to oppose each other, a compromise in the degree of each is necessary in the design of fuel injection equipment, particularly if uniform distribution of fuel within the combustion chamber is to be obtained.

The pressure required for efficient injection, and, in turn, proper dispersion, is dependent upon the compression pressure in the cylinder, the size of the opening through which the fuel enters the combustion space, the shape of the combustion space, and the amount of turbulence created in the combustion space. (Detailed information concerning the last two factors can be obtained from chapter 7 of *Engineman 3*, NavPers 10539.)

TYPES OF DIESEL ENGINE FUEL INJECTION SYSTEMS

The function of the fuel injection system, mentioned in the preceding section, is carried out by a system which may be of the air injection type or of the mechanical (solid) type. However, since few air injection systems are now in use, only systems of the mechanical injection type will be discussed in this chapter.

Mechanical injection systems may be subdivided into three main groups: (1) COMMON-RAIL, (2) INDIVIDUAL-PUMP, and (3) DISTRIBUTOR systems. The first two types of systems may be further subdivided; the common-rail system may be divided into the basic system and a modification, such as that used in Cooper-Bessemer engines. The individual-pump system may be divided into the original system, with a separate pump and fuel injector for each cylinder, and a modification, in which the pump and injector are combined in one unit. These systems, together with the distributor system, will be discussed in the sections which follow.

Common-Rail Injection System

The BASIC COMMON-RAIL SYSTEM consists of a high-pressure pump which discharges fuel into a common rail, or header, to which each fuel injector is connected by tubing. A spring-loaded bypass valve on the header maintains a constant pressure in the system, returning all excess fuel to the fuel supply tank. The fuel injectors are operated mechanically, and the amount of oil injected into the cylinder, at each power stroke, is con-

trolled by the lift of the needle valve in the injector. The principal parts of a basic common-rail system are shown in figure 6–1.

The pressure regulator, which functions as a relief valve, is generally built integral with the high-pressure pump. When the engine load drops off, the fuel consumption decreases and the valve bypasses the difference in the amount of oil delivered by the pump and that consumed by the engine. When load is added, resulting in an increased fuel consumption, the amount of bypassed oil is reduced.

The spray or injection nozzle extends from the top of the cylinder head down into the combustion area. It consists essentially of a multi-hole spray tip, a valve seat, and a needle valve extending the full length of the nozzle and held to its seat by a spring. The high pressure is conducted from the fuel header to the spray tip, immediately above the valve seat. When the needle

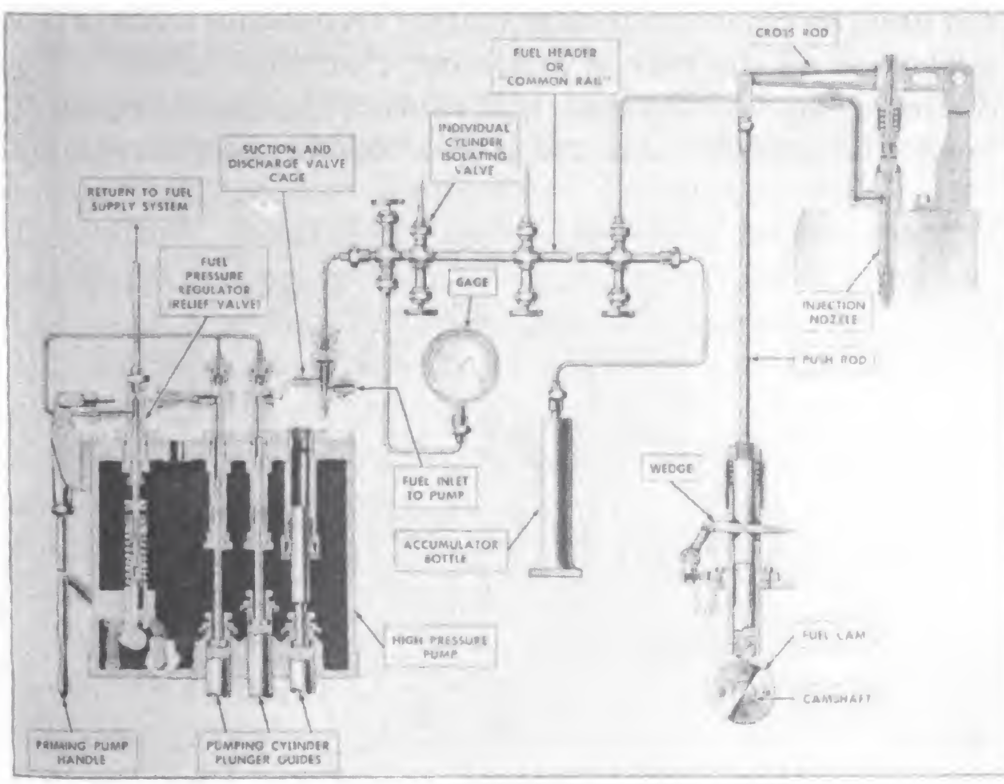


Figure 6–1.—Basic common-rail system (Cooper-Bessemer).

valve is lifted vertically from its seat, fuel is sprayed into the combustion chamber.

The duration of the injection period depends upon the length of time the valve is off its seat, and the quantity of fuel injected depends upon the duration, the size and number of holes in the tip, and the operating pressure. The needle valve is lifted mechanically by a system of push rods and cross rods, actuated by a timed camshaft. The duration period of the needle valve opening is dependent upon the clearance existing between the cam and push rod mechanism. A minimum clearance promotes a greater needle valve lift, and a maximum clearance carried to the extreme will not even transmit the cam lift to the needle valve, as is the case when the throttle is in the "OFF" position. This control of the amount of clearance, which affects cam lift, is accomplished by means of a wedge mechanism, generally placed between the cam and push rod mechanism (fig. 6–2). However, on some engines this wedge is located between the cross rod and the injection needle valve. When the wedges are pushed in all the way, a minimum clearance exists. The inclined plane of the cam will contact the needle opening push rod sooner and raise the nozzle needle earlier.

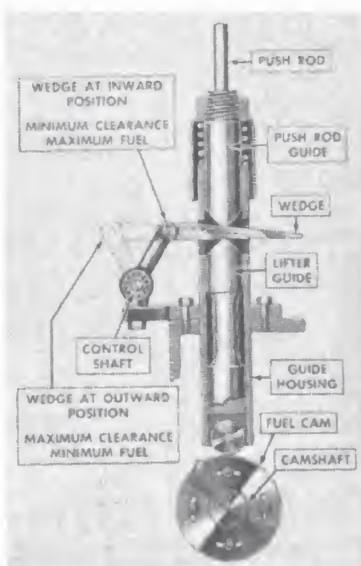


Figure 6–2.—Fuel control mechanism.

Since the contour of the closing side of the cam is usually the same as that of the opening side, the needle returns to its seat an equal number of crankshaft degrees late to degrees early in opening.

The wedges are attached to a single shaft which is coupled to the governor or engine throttle, depending on the service of the engine. The wedges are consequently moved in or withdrawn as the engine load changes to increase or decrease cam to push rod clearance, and vary the duration of injection, as needed, to meet the demands of the engine.

The beginning and ending of the injection period vary with the duration. This improves engine performance, since a shorter duration retards the beginning of injection timing which is advantageous in starting the engine or when running at light loads. The seat of the injection nozzle is required to hold injection pressure. It is essential that this valve is properly seated, otherwise fuel will enter the cylinder out of time and result in detonation and smoky exhaust.

An isolating valve is located in the line from the common header to each nozzle. This individual cylinder isolating valve permits shutting off any one of the nozzles. In addition, the fuel injection system has an accumulator bottle on the pressure side of the pump; this increases the volume of fuel in the system. This large volume of oil dampens the pumping pulsations and maintains a constant supply on the header.

The common-rail system is not suitable for high-speed, small-bore engines because it is difficult to control accurately the small quantities of fuel injected into each cylinder at each power stroke

The MODIFIED COMMON-RAIL SYSTEM, sometimes referred to as the controlled-pressure system, differs from the basic system in that mechanically operated fuel injectors are included, and the nozzles are operated hydraulically instead of mechanically. The nozzles of the

modified system, shown in figure 6–3, do not meter the fuel; instead, the fuel is metered by the injectors. In addition, pressure regulation is accomplished by the high-pressure pump, instead of by a pressure regulator.

The pump plunger, on its downward stroke, first closes small holes that connect the pump barrel with the fuel admission line. Additional downward motion increases the oil pressure in the pump until it opens the spring-loaded discharge valve and delivers the oil into the injection system. During the return stroke, the spring moves the plunger upward; this creates a vacuum, and when the plunger uncovers the holes on top, oil from the suction side enters into the pump. The oil from the fuel-oil pressure tank, on its way to the suction side of the pump, is admitted first to the inner side of a sleeve (sleeve valve). The inner and outer sleeves (fig. 6–3) have two mating holes. By turning the sleeves, one relative to the other and to the housing, the amount of fuel admitted

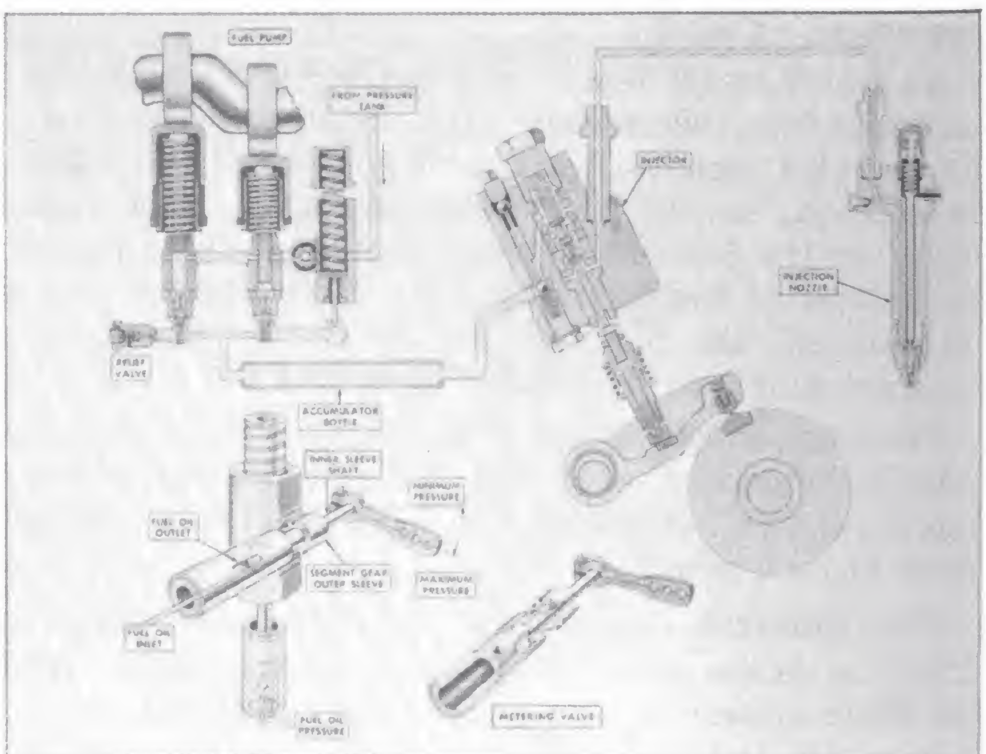


Figure 6–3.—Modified common-rail injection system (Cooper-Bessemer).

to the pump is adjusted to meet the load and speed requirements. The outer sleeve is set and turned by the governor so as to admit a sufficient amount of fuel to correspond to the load carried by the engine. The inner sleeve is turned by a mechanism set to maintain a prescribed constant pressure in the system. If the pressure goes up, the sleeve is turned to decrease the effective area of the opening between the two sleeves. The amount of fuel taken by the pump is thus reduced, and as a result the pressure in the system is decreased. On the other hand, when the pressure begins to drop, the sleeve is turned in the opposite direction, the effective opening area is increased, more fuel goes into the pump, and the pressure goes up.

The injection nozzle consists of a spring-loaded plunger with a conical end which acts as a valve. When the injection nozzle valve is raised from its seat by the oil pressure, the valve is opened. When the oil pressure drops, the spring-loaded injection nozzle valve is returned to its seat, closing the valve. A quick closing of the injection nozzle and elimination of after-dribbling of the fuel into the combustion space is obtained as follows: the lifter plunger is drilled lengthwise at its center from the valve end to a point in line with the recess in the injector body (fig. 6–3). Another hole, drilled at a right angle to the central hole, connects with it, forming a passage from the lifter end to the recess and through it to the drain tank. The bottom of the injector valve is lapped to a seat with the end of the lifter plunger so that when the two are brought in contact during injection, the passage through the plunger is sealed. As soon as the fuel cam releases the lifter plunger, the valve is closed by its spring (fig. 6–3). The oil pressure on the end of the lifter plunger will move it downward, and a small amount of fuel oil is spilled to the drain tank, relieving the oil pressure in the nozzle. The lifter spring will then return the lifter plunger to a contact with the valve. This arrangement also acts as a safety feature which prevents

passage of the fuel oil into the engine cylinder, except when necessary, even if the injector valve should leak at its seat.

The advantage of this system over the basic common-rail system is that little effort is required to adjust the operating pressure. Therefore, this system can be attached to the engine governor or throttle, whereby the pressure automatically changes with load or speed. (In the basic system, it is necessary to manually adjust the spring force of the pressure regulator.)

Pump-Injection Systems

Individual-pump injection systems of the original jerk pump, or basic, type include high-pressure pumps and pressure-operated spray valves or nozzles which are separate units. In some engines, only one pump and nozzle are provided for each cylinder. In other engines, such as the Fairbanks-Morse (FM 38D), each cylinder is provided with two pumps and two nozzles. (Such an arrangement can be found in *Engineman 3,* NavPers 10539, or in the appropriate manufacturer's instruction book.)

Of all the individual-pump injection systems used by the Navy, the modified system is the most compact. A high-pressure pump and an injection nozzle for each cylinder are combined into one unit. This type of unit, generally used with General Motor (GM) engines, is often referred to as a unit injector. These systems will be discussed in the sections which follow.

Bosch Fuel System. This injection system is used on many of the Navy's Diesel engines, such as the Hercules and Superior engines. Figure 6–4 illustrates the fuel piping of the Hercules DWXD-S engine with a Bosch fuel injection system and governor. A FUEL SUPPLY PUMP, on the side of the injection pump housing, draws fuel from the SUPPLY TANK and through a duplex FUEL OIL STRAINER. (The duplex oil strainer in the Hercules oil system is similar to the other strainers described in

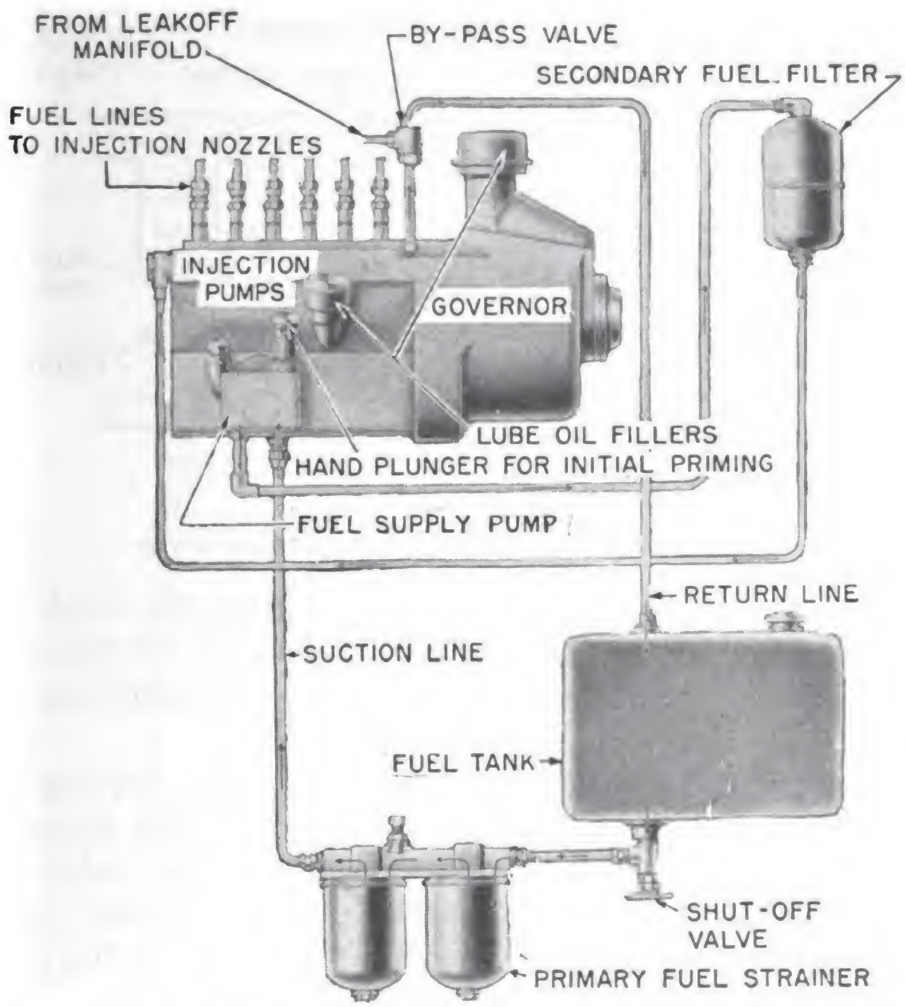


Figure 6–4.—Fuel piping system with Bosch injection pump and governor.

Engineman 3, NavPers 10539.) Oil is first discharged from the supply pump to a FUEL OIL FILTER and then to the INJECTION PUMPS. The supply pump furnishes an excess of oil to the injection pumps, and this excess is returned, through a BYPASS VALVE and RETURN LINE, to the supply tank.

The FUEL SUPPLY PUMP, mounted directly on the injection pump housing, is driven by one of the cams on the injection pump camshaft. It is a plunger type pump which is self-regulating to build up only a certain maximum pressure. The operation of this fuel pump is illustrated in figure 6–5.

In figure 6–5A, the plunger is near the end of a suction

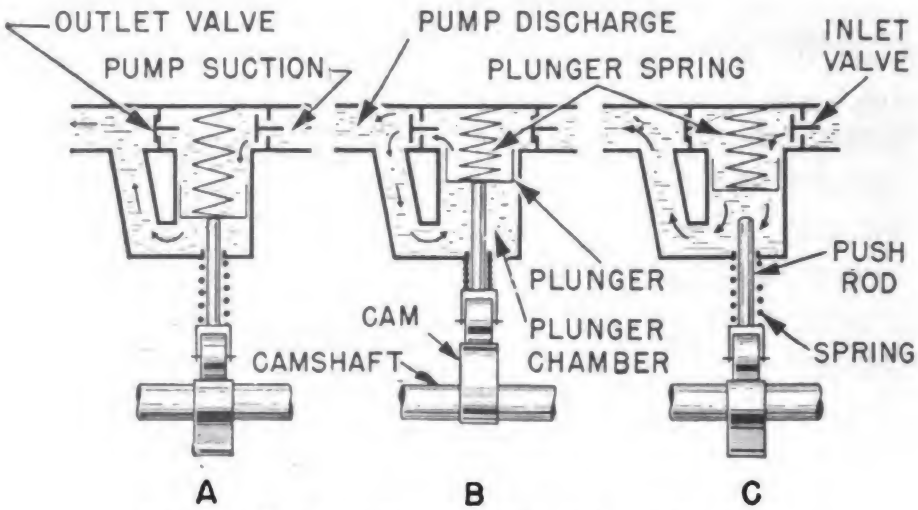


Figure 6–5.—Operation of Bosch fuel supply pump.

stroke in which fuel is being forced from the discharge line to the filter and the injection pump. At the same time the movement of the plunger draws additional oil through the inlet valve.

In figure 6–5B, the cam has moved up, driving the plunger against its spring. The oil above the spring is placed under pressure which closes the inlet valve and opens the outlet valve. As the plunger moves, oil is forced through the outlet valve, and also fills up the space in back of the plunger.

In figure 6–5C, the cam has rotated out from under the plunger push rod, which is returned by the push rod spring. This releases the compression force on the plunger spring, which expands to drive the plunger back. This return plunger movement is the pumping stroke, with oil discharging to the filter and the injection pump, and new oil is drawn in from the strainers and the supply tank.

The supply pump push rod continues to reciprocate with the cam action, moving up and down once every two engine revolutions (camshaft speed in a four-cycle engine).

Figure 6–6 is a phantom view of the Bosch fuel supply pump, showing the actual positions of the parts which are indicated in figure 6–5.

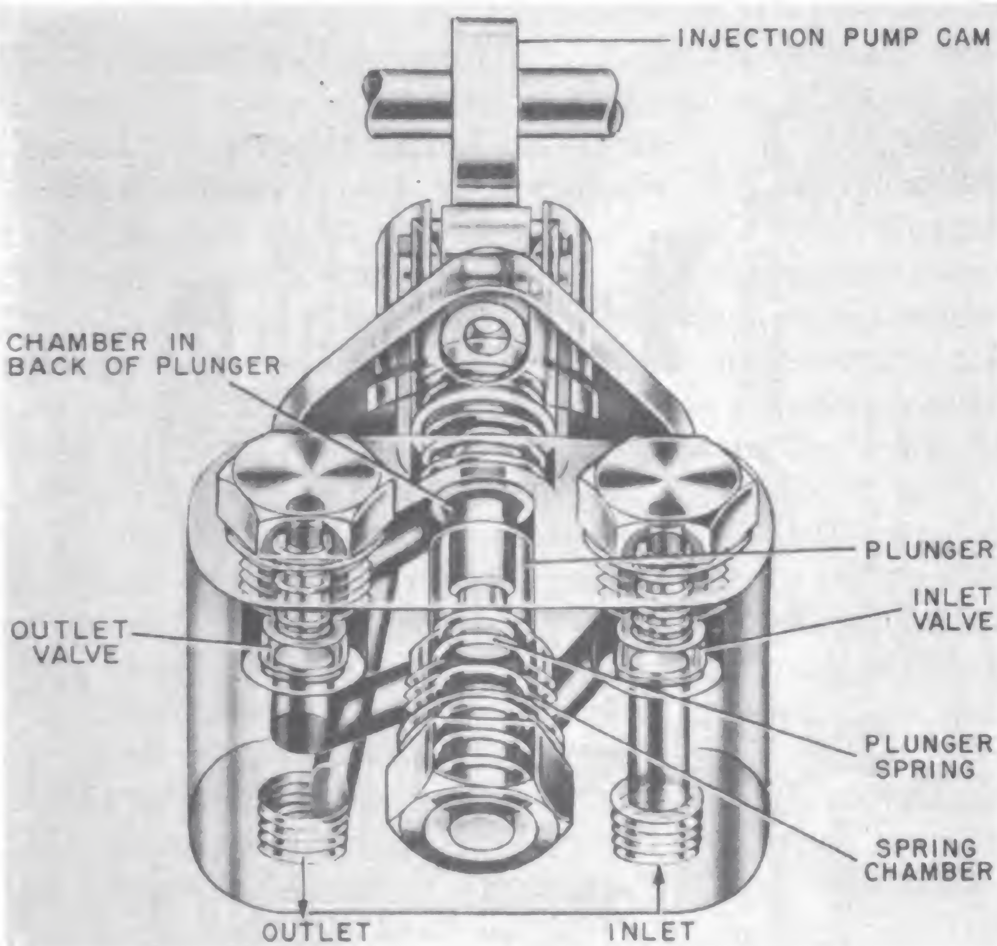


Figure 6–6.—Phantom view of Bosch fuel supply pump.

BOSCH FUEL INJECTION PUMPS are of two basic designs—type APE and type APF pumps. Figure 6–7 illustrates the two types of injection pumps, together with high-pressure lines and spray nozzles.

Types APF pumps are single cylinder designs, the plunger pump for each cylinder being in a separate housing. In a six-cylinder engine, for example, there would be six separate APF pumps. Each pump is cam-driven and regulated by an individual control rack.

Type APE pumps are assembled with all the individual cylinder plungers in a single housing. The left side of figure 6–7 shows the pump assembly for a six-cylinder engine. The injection pumps are operated from a single camshaft in the bottom part of the housing. The cams

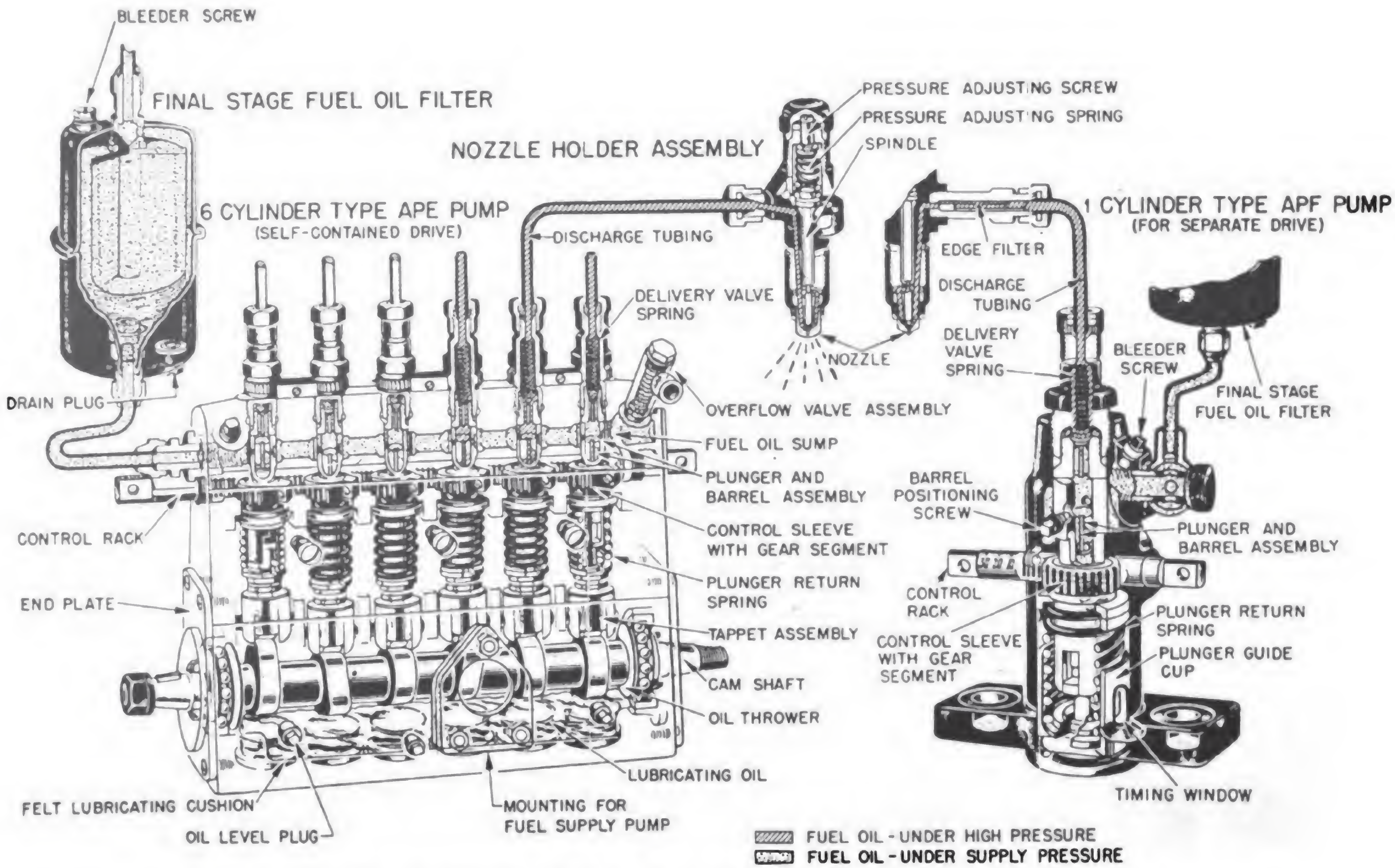


Figure 6–7.—Phantom views of APE and APF Bosch fuel injection pumps.

dip into lubricating oil and brush against felt cushions at the bottom of each revolution. At the top of each revolution, the cams force the spring-loaded plungers up against the plunger spring resistance.

Each plunger moves up and down in a barrel which contains fuel oil at the supply pressure. The plunger traps oil above it during part of the upward stroke and forces it through the delivery valve and high-pressure tubing to the spray nozzle, where it is injected into the combustion chamber. The action of the plunger, control rack, delivery valve, and spray nozzle are the same in both APE and APF types of pumps.

By studying figure 6–7, you can obtain a better understanding of the fuel injection mechanism and the control of the amount of fuel injected. The fuel oil sump is filled with clean oil from the supply pump and fuel oil filter. Oil enters the barrel above the plunger through a pair of ports.

The amount of fuel forced out through the spray nozzle on each upward stroke of the plunger depends on how the plunger is rotated. In figure 6–7, you will notice that the control rack has teeth all along the side, meshing with a gear segment on each pump. Lengthwise movement of the control rack rotates all the plungers the same direction and the same amount. Rotation of the plungers changes the part of the plunger helix that passes over the spill port (on the right side of each barrel in fig. 6–7), and this changes the time at which injection ends.

The pumping principle of the Bosch pump is illustrated by figure 6–8, in which four steps of a pumping stroke are shown. In figure 6–8A, the plunger is below the inlet and spill ports. Fuel oil enters the barrel, as indicated by the dotted white arrow, and fills the barrel chamber, between the plunger and the delivery valve.

The plunger has a flat top, and the two ports are set at the same level. This means that the two ports are closed by the plunger at exactly the same moment as the plunger

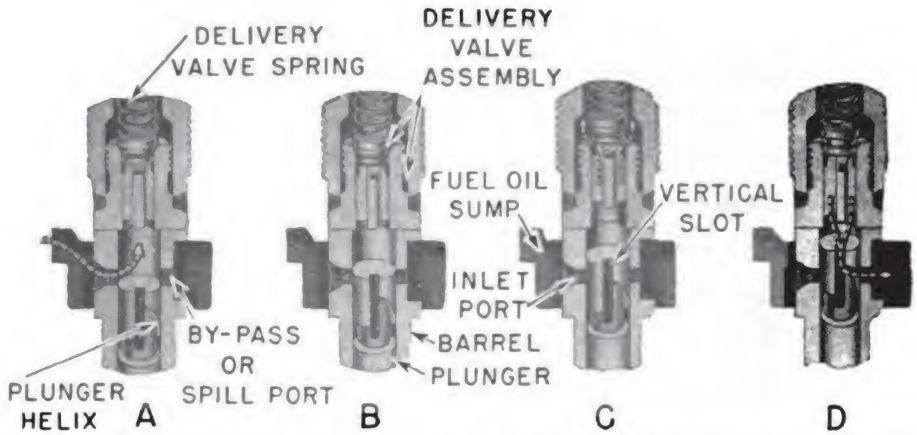


Figure 6–8.—Upward stroke of Bosch plunger, showing pumping principle.

travels upward. In figure 6–8B, the ports are just closed. The fuel above the plunger is trapped and placed under high pressure by the rising plunger. The pressure forces the delivery valve up at once, allowing the high pressure oil to go to the spray nozzle.

In figure 6–8C, the plunger is in the effective part of its stroke, with both ports closed. Fuel is passing through the delivery valve to the spray nozzle. The effective stroke will continue as long as both ports remain covered by the plunger.

At the moment the spill port is uncovered by the edge of the helix, as shown in figure 6–8D, fuel injection ends. As soon as the port is opened, the fuel oil above the plunger flows out through the vertical slot in the plunger and goes to the low-pressure fuel oil sump. This releases the pressure above the plunger and the delivery valve is returned to its seat by the valve spring.

The effect of plunger rotation on fuel delivery is shown in figure 6–9A. In figure 6–9B, the plunger is rotated to bring the vertical slot to the edge of the inlet port, which is the setting for maximum delivery. In this plunger position, the lowest part of the helix is in line with the spill port. This makes the longest possible effective stroke before the spill port is uncovered, ending the injection of fuel.

In figure 6–9C, the plunger is rotated to move the vertical slot half way around toward the spill port. This

brings a higher part of the helix in line with the spill port, and leaves a short effective stroke before the spill port is uncovered. This is the setting for medium, or normal, delivery.

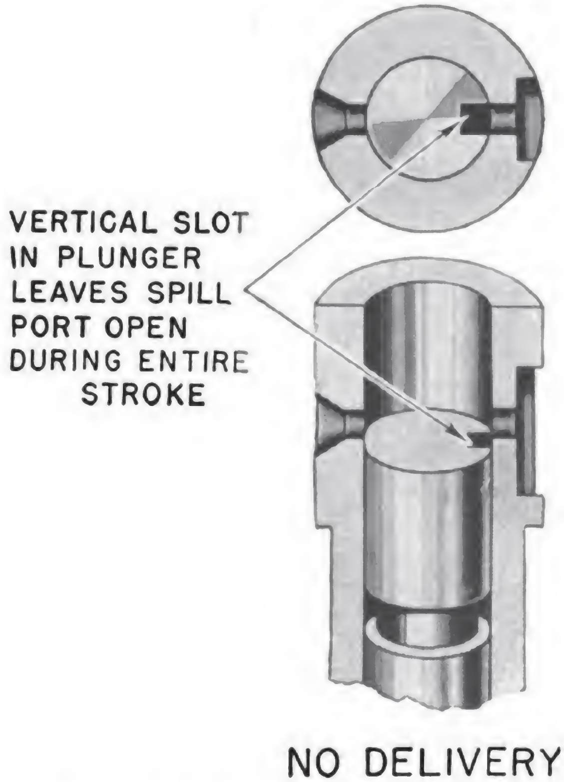


Figure 6–9(A).—Effect of plunger rotation on fuel delivery.

The position of no fuel delivery is reached when the plunger has been rotated to bring the vertical slot in line with the spill port (fig. 6–9A). In this plunger position, the fuel above the plunger will not be under compression during any part of the upward stroke.

The amount of fuel injected can be regulated by setting the plunger in any position between no delivery and maximum delivery. The plunger setting is controlled by the position of the control rack, which regulates all the plungers at the same time. Movement of the control rack, either manually or by governor action, rotates the plunger and varies the quantity of fuel delivered by the pump.

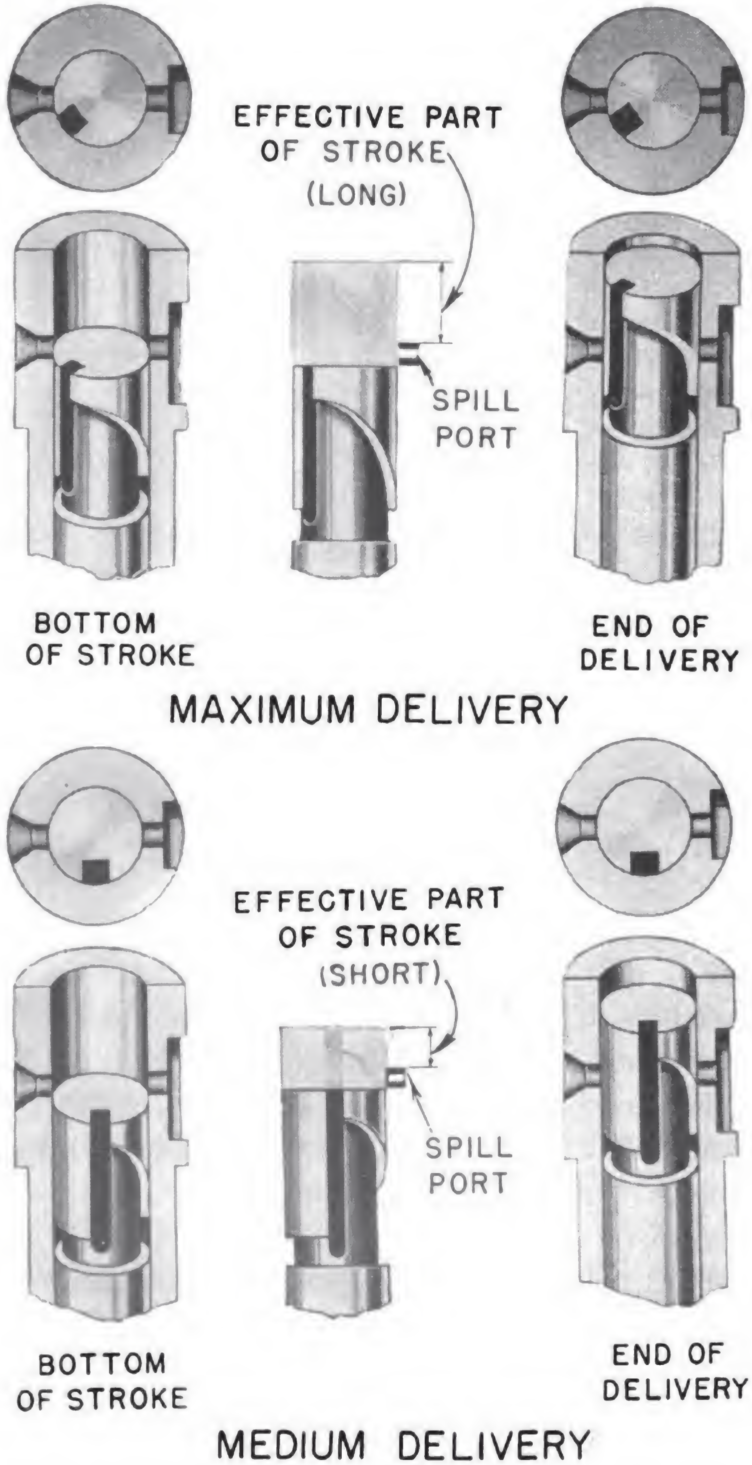


Figure 6–9(B&C).—Effect of plunger rotation on fuel delivery.

Figure 6–10 illustrates a cutaway of the Bosch injection pump and control rack assembly. The GEAR SEGMENT is secured to the CONTROL SLEEVE, which is free to rotate on the stationary BARREL. The control sleeve has a slot at the bottom into which the PLUNGER FLANGE fits. The flange moves in the slot as the plunger moves up and down. When the CONTROL RACK is moved lengthwise, the gear segment and the control sleeve rotate around the outside of the barrel. The plunger flange and the plunger (inside the barrel) follow the rotation of the control sleeve.

The Bosch plunger described in figures 6–8, 6–9, and

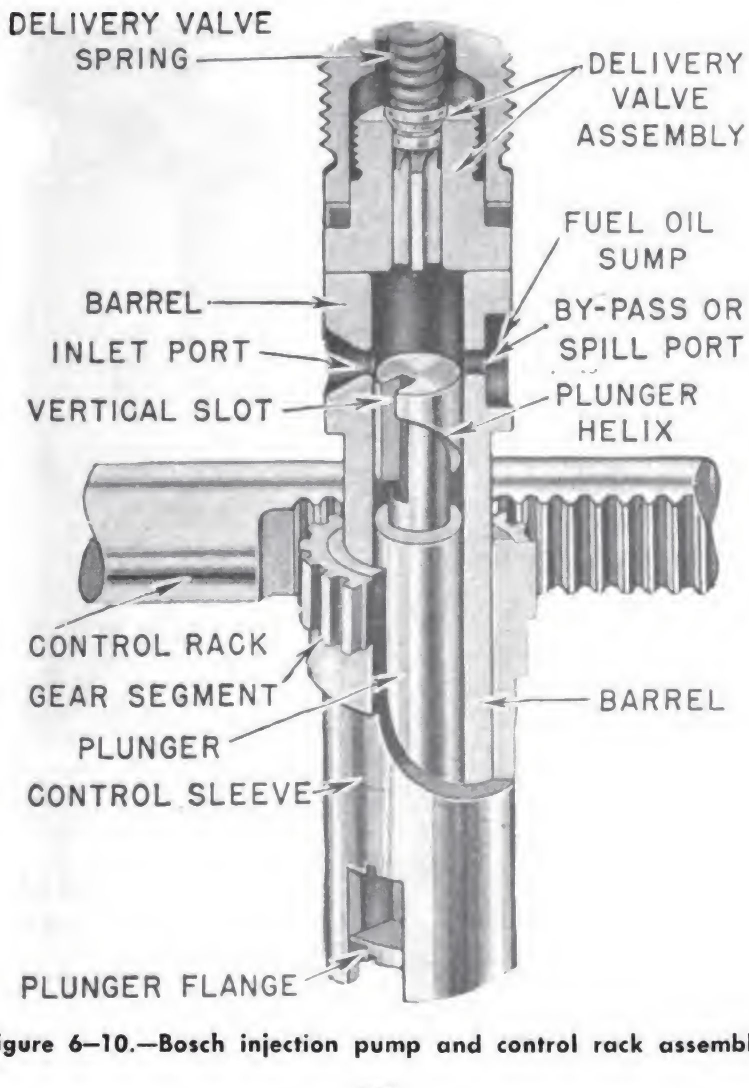


Figure 6–10.—Bosch injection pump and control rack assembly.

6–10 has a flat top surface and a lower helix. With this type of plunger, fuel injection will always begin at the same point in the piston cycle, whether it is set for light load or heavy load. Injection begins when the ports are closed, and the end of injection can be varied by plunger rotation. This type of plunger is used in pumps marked "Timed for port closing." Injection has a constant beginning and variable ending.

Another type of Bosch plunger has an upper helix. Rotation of the plunger varies the beginning of the effec-

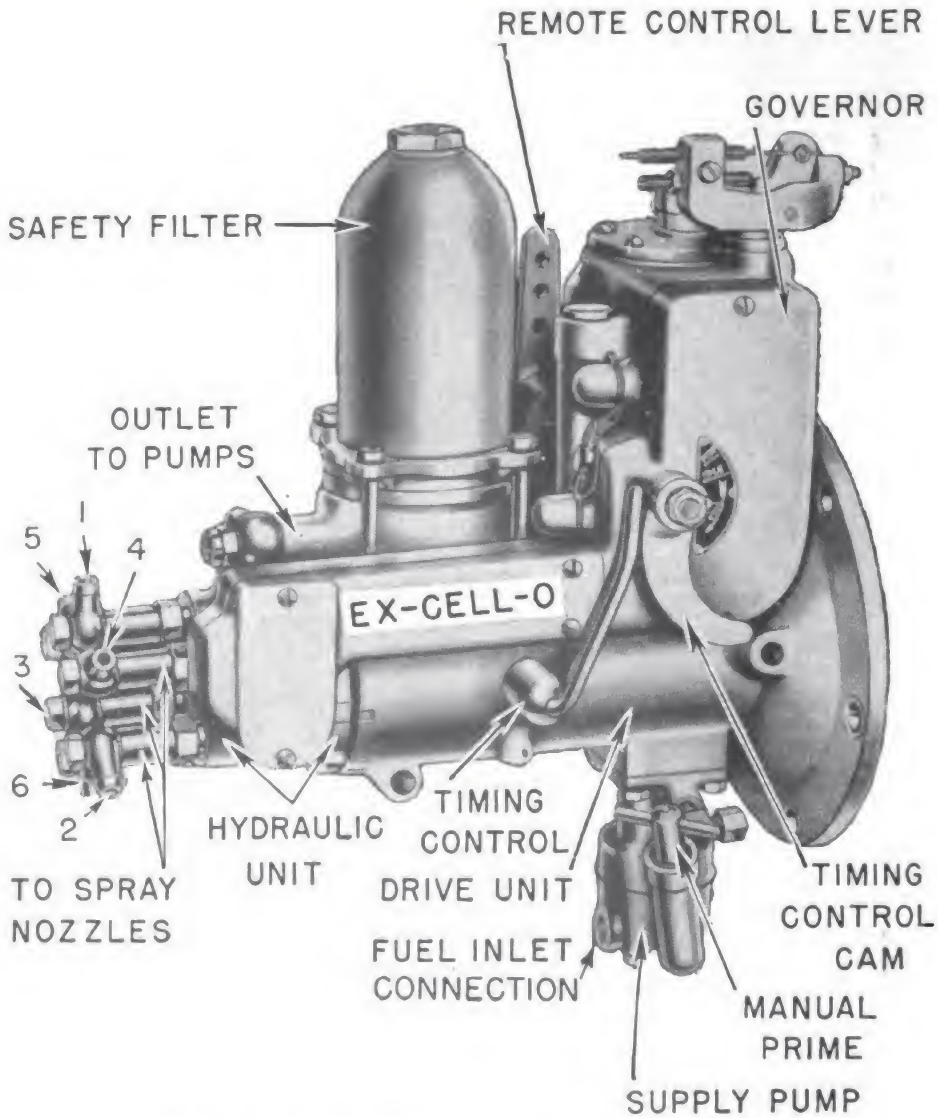


Figure 6–11.—Ex-Cell-O pump and governor unit

tive stroke, while the ending is constant. This type of plunger is used in pumps marked "Timed for port opening."

A third type of plunger has both upper and lower helixes. Rotation of this type of plunger varies both the beginning and ending of injection.

Ex-Cell-O Fuel System. The Ex-Cell-O fuel system is used on the Navy type Diesel engines for power boats. This fuel system is similar to the Bosch APE fuel system, having a supply pump, a governor, and high-pressure injection pumps built into a single assembly. However, the method of working the high-pressure plungers and the method of measuring the fuel to be injected are much different from those used with the Bosch system. The Ex-Cell-O assembly (supply pump, injection pump, filter, and governor) is shown in figure 6–11, and a cutaway view of the injection pump and filter is shown in figure 6–12.

The DRIVE GEAR (fig. 6–12) is driven by the gear train,

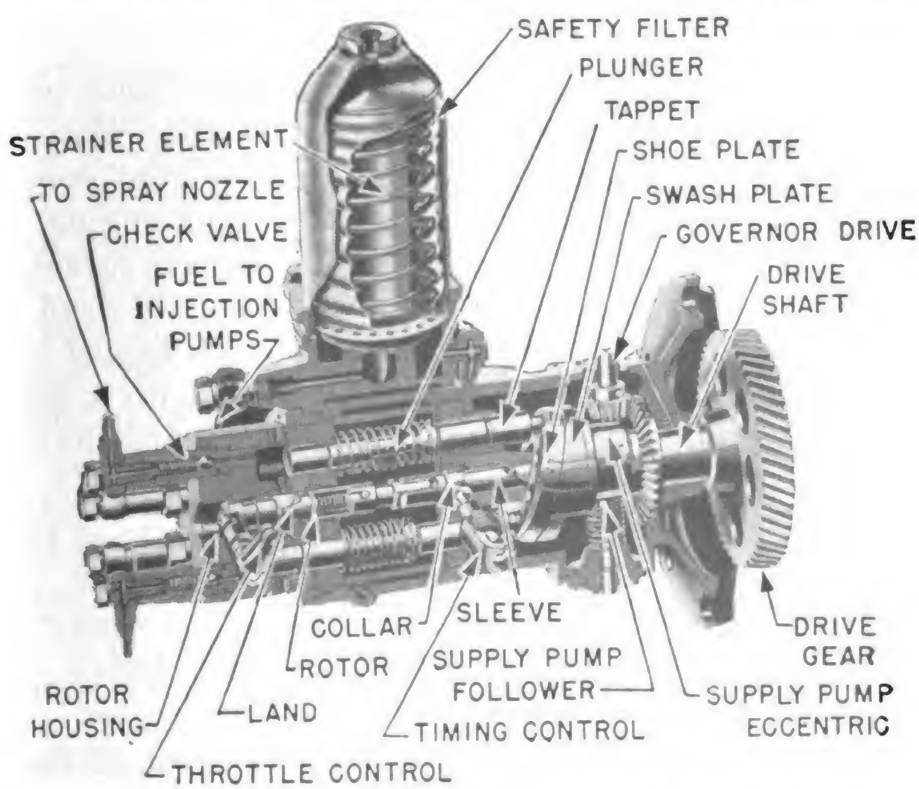


Figure 6–12.—Cutaway view of Ex-Cell-O injection pump and filter.

and furnishes the power for the rest of the fuel supply system. An eccentric on the drive shaft operates the fuel supply pump. The action of this fuel supply pump is similar to that of the Bosch pump.

The supply pump sends oil, under an approximate pressure of 25 psi, to the SAFETY FILTER. This filter consists of two elements; outer and inner elements. The outer element is made of wool fabric, which removes dirt particles that may get through the main supply filter. The oil then goes through the walls of the inner element, which is a metal edge strainer. All particles larger than 0.0015-inch are caught by the strainer, and the clean oil then flows to the fuel chambers of the injection pumps.

As far as the INJECTION PUMP is concerned, the plungers are not cam-operated as they are in the Bosch pump. Instead, they are made to move back-and-forth by means of a rotating SWASH PLATE, keyed to the drive shaft. The surface of the swash plate is cut at an angle to the drive shaft. The stationary SHOE PLATE bears against the inclined surface of the swash plate.

Now, picture what happens to the shoe plate as the swash plate rotates; any point on the shoe plate will move back and forth. This is the motion that operates the injection plungers. For a six-cylinder engine (fig. 6–12), the shoe plate has six equally spaced sockets on the side away from the swash plate. The ball head of a TAPPET fits into each of the sockets. Each tappet bears against a PLUNGER which is closely fitted into a barrel. (Two of the plungers are shown in fig. 6–12 and the other four are omitted to make the illustration clearer.)

The back-and-forth motion of the shoe plate is transferred to the plungers against spring resistance. The plungers force oil out to the spray nozzles, where it is injected into the combusion chambers under high pressure.

The mechanism for measuring the amount of fuel to be injected at each plunger stroke is quite different from

that of the Bosch pump or the unit injector (discussed later in the chapter). Measuring is done by the centrally located ROTOR, which is driven by the drive shaft. To understand how the rotor meters the fuel for injection, refer to figure 6–13 which shows four successive stages in the injection cycle of the Ex-Cell-O pump.

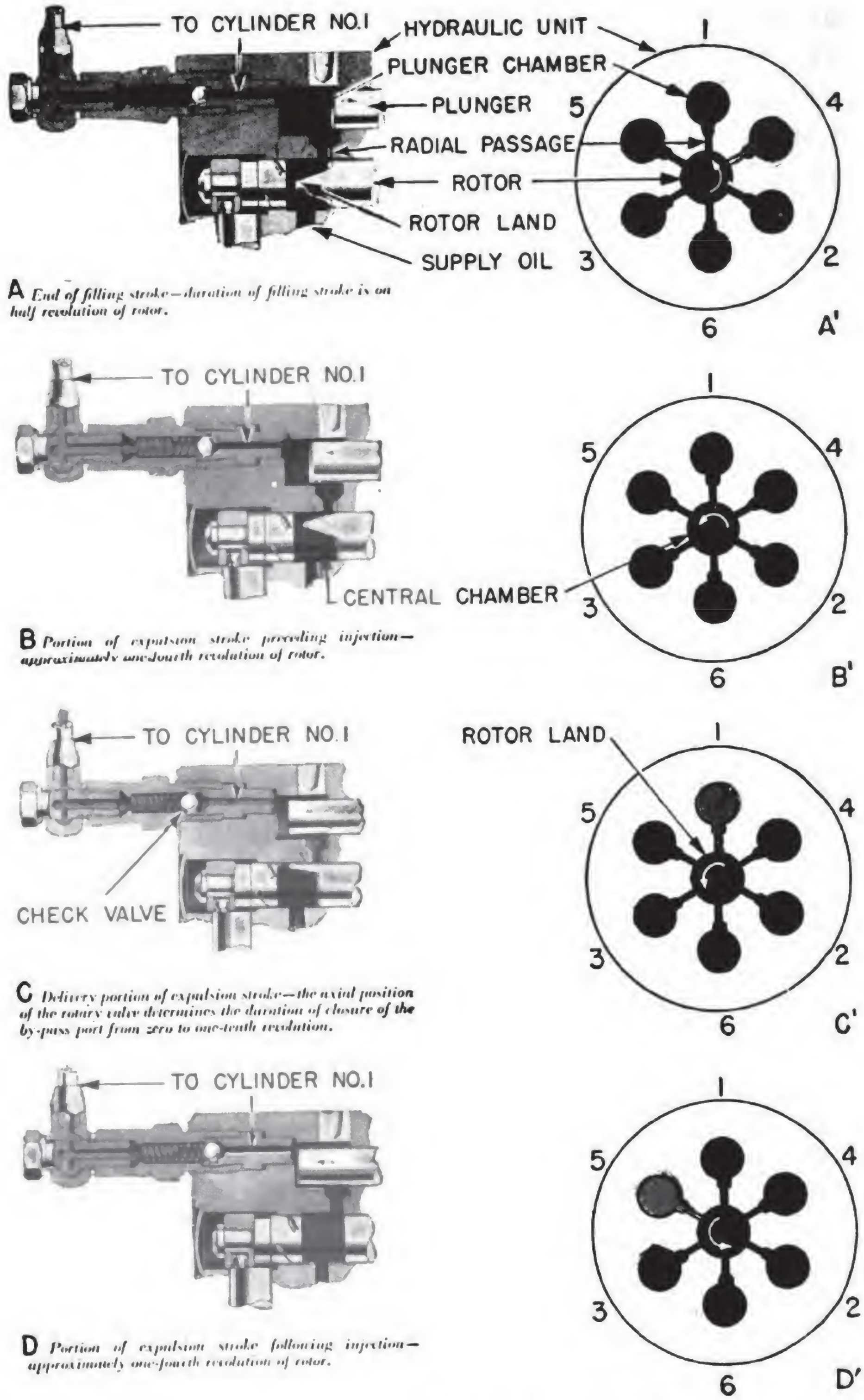
On the left side of figure 6–13, there are four cutaway views of the HYDRAULIC UNIT (A, B, C, D) which show the rotation of the rotor to four successive positions, and also the mechanism of pumping high pressure oil to cylinder No. 1. For the time being, concentrate on these four views before proceeding with the discussion.

Low pressure supply oil from the safety filter enters the hydraulic unit and fills the central FUEL CHAMBER. This chamber is a space where the rotor shaft is cut away to a smaller diameter than the rest of the shaft, except for a triangular segment called the ROTOR LAND (fig. 6–13A). The land makes a close fit with the wall of the fuel chamber. As the shaft rotates, the land sweeps around the inside wall of the fuel chamber, covering successively new portions of the wall. Follow the position of the land in views A, B, C, and D.

The PLUNGER above the rotor in these views is one of the six which are given a back-and-forth motion by the swash plate. In view A, the plunger is moving to the right. This increases the volume of the PLUNGER CHAMBER, so that supply oil flows from the central chamber, through the RADIAL PASSAGE (bypass port), into the plunger chamber.

In view B, the plunger is moving to the left and oil is flowing, from the plunger chamber, back into the central chamber. As the rotor turns, the land moves closer to the radial passage.

In view C, the rotor land has moved over the radial passage, and the oil remaining in the plunger is trapped there. The plunger continues moving to the left, and the oil is placed under high pressure. This oil is forced through the check valve and the fuel line to the cylinder



A *End of filling stroke—duration of filling stroke is one half revolution of rotor.*

B *Portion of expulsion stroke preceding injection—approximately one-fourth revolution of rotor.*

C *Delivery portion of expulsion stroke—the axial position of the rotary valve determines the duration of closure of the by-pass port from zero to one-tenth revolution.*

D *Portion of expulsion stroke following injection—approximately one-fourth revolution of rotor.*

Figure 6–13.—Mechanism of the Ex-Cell-O fuel injection pumps.

(No. 1), where it is injected into the combustion chamber.

In view D, the rotor land has rotated away from the radial passage and the oil in the plunger chamber can again escape to the central chamber, as the plunger completes its stroke to the left. Injection to cylinder No. 1 ends abruptly at the moment the land begins to uncover the radial passage. The pressure drops immediately to the supply pressure of 20–25 psi, the check valve slams shut, and the spray nozzle valve closes abruptly.

Refer to the diagram A′, B′, C′, and D′, on the right side of figure 6–13. Each diagram represents a cross-section of the hydraulic unit of the Ex-Cell-O fuel injection pumps, cut at the level of the radial passages between the central chamber and the plunger chambers. In addition, each diagram corresponds to the cutaway view to the left of the figure.

In diagram A′, the rotor land is covering the radial passage to plunger chamber No. 4. The oil in this chamber is under high pressure as the plunger is forced outward by the swash plate, and the oil is being injected into cylinder No. 4.

In diagram B′, the rotor land is between the radial passages to plunger chambers 4 and 1. The oil is not under pressure in any chamber, and no injection is taking place.

In diagram C′, the rotor land has covered the radial passage to fuel chamber No. 1, and the oil in this chamber is under high pressure. This is also shown in view A, at the left of this diagram. Injection is occurring into cylinder No. 1.

In diagram D′, the rotor has covered the radial passage to fuel chamber No. 5, and the oil in this chamber is under high pressure. Injection is occurring into cylinder No. 5.

Figure 6–13 follows the rotation of the rotor through only one-half of a revolution. In the diagram, you can

notice that the rotor land has covered the radial passages to fuel chambers 4–1–5, in that order. In the next half-revolution, the remaining three passages will be covered—3–6–2. In other words, as the rotor turns, the land covers the passages in the order 1–5–3–6–2–4; this is a firing order.

Let us consider a power boat Diesel, Navy type DB, running at a constant speed of 1,000 rpm. The Ex-Cell-O fuel pump rotor will be turning at 500 rpm (half engine speed in a four-cycle engine). The swash plate also rotates at half engine speed and forces the six plungers outward in their pumping strokes in succession, 60° apart. The rotor is timed to cover the radial passage to each plunger chamber while the plunger is in its outward stroke.

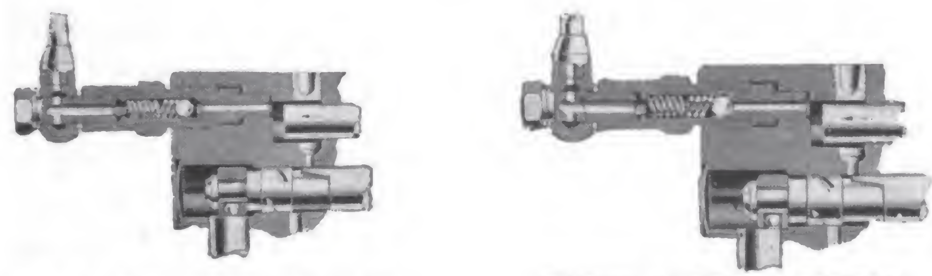
The outlets from the Ex-Cell-O pump to the spray nozzles are numbered in figure 6–11. (Notice that the numbers are in the firing order, 1–5–3–6–2–4.)

As far as Ex-Cello-O TIMING and FUEL REGULATION are concerned, there are two separate controls for regulating the amount of fuel which is injected at each plunger stroke—the THROTTLE CONTROL and the TIMING CONTROL (fig. 6–12). The timing control also adjusts the time of injection in the engine piston cycle.

The TIMING CONTROL is hand-operated by means of the REMOTE CONTROL CAM (fig. 6–11). Moving the remote control lever to the right in figure 6–11 would cause the timing control to rotate counterclockwise. The timing control shaft has an off-set, or eccentric, spherical-headed pin which rests in a hole on the COLLAR (fig. 6–12). This movement of the collar pushes the entire rotor shaft to the left, increasing the fuel injection and advancing the injection period.

Movement of the rotor shaft to the left increases the amount of fuel injected, because the wider parts of the rotor land are brought over the radial oil passages (fig. 6–14). This keeps those passages closed longer and injection lasts longer during the plunger stroke. The

reverse movement of the remote control lever brings the narrower parts of the rotor land over the radial passages and decreases fuel injection. In figure 6–14B, the rotor shaft has been moved all the way to the RIGHT. This is the STOP POSITION because the land does not cover the radial passage. In figure 6–14A, the rotor is moved to the left from the stop position, and the narrowest part of the land covers the radial passage for a very short injection period. The speed indicator plate in figure 6–11 shows you that pushing the remote control lever all the way to the left stops the engine, while pushing the lever to the right gives full-load injection.



ROTOR POSITIONS AT IDLE AND LIGHT LOADS
A

ROTOR IN STOP POSITION
B

Figure 6–14.—Fuel regulation in Ex-Cell-O pump.

In addition to regulating the amount of fuel, the timing control advances and retards the injection period. (This timing adjustment should not be confused with fuel regulation.) When you increase fuel, you merely spread out the injection period—injection begins earlier and ends later. However, when the timing control shifts the rotor assembly to the left and the fuel is increased, the whole rotor assembly is made to rotate slightly, with respect to the drive gear and the swash plate. The SLEEVE in figure 6–12 has a spiral slot in which you see a pin through the rotor driving shaft.

The torque of the driving shaft is transmitted to the sleeve and to the rest of the rotor assembly by the pin. When the timing control shifts the collar to the left, the

sleeve moves to the left along the rotor driving shaft, which remains secured to the center of the swash plate. The pin follows the spiral slot in the sleeve, so that the sleeve must rotate a small amount. This rotation of the sleeve turns the entire rotor assembly so that the rotor land reaches each radial passage earlier in the piston cycle—that is, a few more degrees before top dead center. The reverse shift of the timing control collar retards the injection period.

The THROTTLE CONTROL (fig. 6–12) is operated entirely by the governor. An eccentric pin engages a stationary collar, as in the timing control. When the collar is shifted, the rotor is simply moved lengthwise, increasing or decreasing the fuel setting of the rotor (fig. 6–14). The throttle control does not advance or retard the injection period.

Unit-Injector System. All General Motors Diesel engines (GM 567, 278, 258, and 71 Series) use the UNIT INJECTOR which combines a pump and a fuel-spray nozzle in one unit, as shown in figure 6–15. Before proceed-

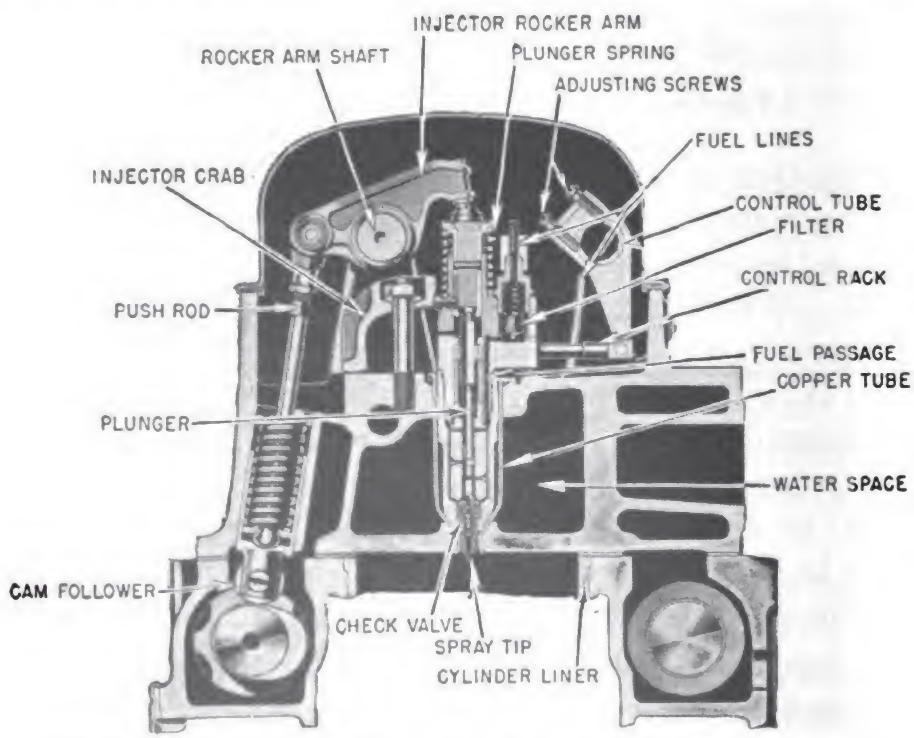


Figure 6–15.—Mounting of the unit injector in the cylinder head.

ing with the injection mechanism, it is important for you to know that the fuel piping to the unit injector carries oil at the filter discharge pressure (generally about 25–30 psi). This arrangement eliminates the need for high-pressure piping.

The unit injector is generally installed in the cylinder head as shown in figure 6–15. It is held in place by an injector crab. The cylinder head has a copper tube into which the injector fits snugly, the spray tip projecting slightly into the cylinder clearance space. Water circulates around the copper tube and cools the lower part of the injector.

Two fuel lines are connected to each injector, one carrying fuel to the injector and the other carrying away oil that is bypassed. The injector is operated by a rocker arm and push rod, which work off the camshaft. The amount of fuel injected is regulated by the CONTROL RACK, which is operated by a lever secured to the CONTROL TUBE.

A sectional view of a unit injector is shown in figure 6–16. The main stationary parts are the BODY, the NUT, and the BUSHING. The nut screws onto the bottom of the body, and the bushing is placed inside the nut. The upper end of the bushing fits inside the lower end of the body and is pressed against the body by a shoulder on the bushing. A GEAR RETAINER also fits inside the body, just above the bushing. The bottom of the bushing rests against the CHECK VALVE ASSEMBLY, in which there are three stationary parts—the SPACER, the VALVE SEAT, and the SPRAY TIP. The check valve assembly is secured against the lower end of the bushing by the nut which is threaded to the body.

Refer to fig. 6–16 and you will notice that the stationary parts leave a hollow core through the length of the injector. In the assembled injector, the core is filled with movable parts which make up the PLUNGER and CHECK VALVE mechanism.

The PLUNGER ASSEMBLY consists of the FOLLOWER

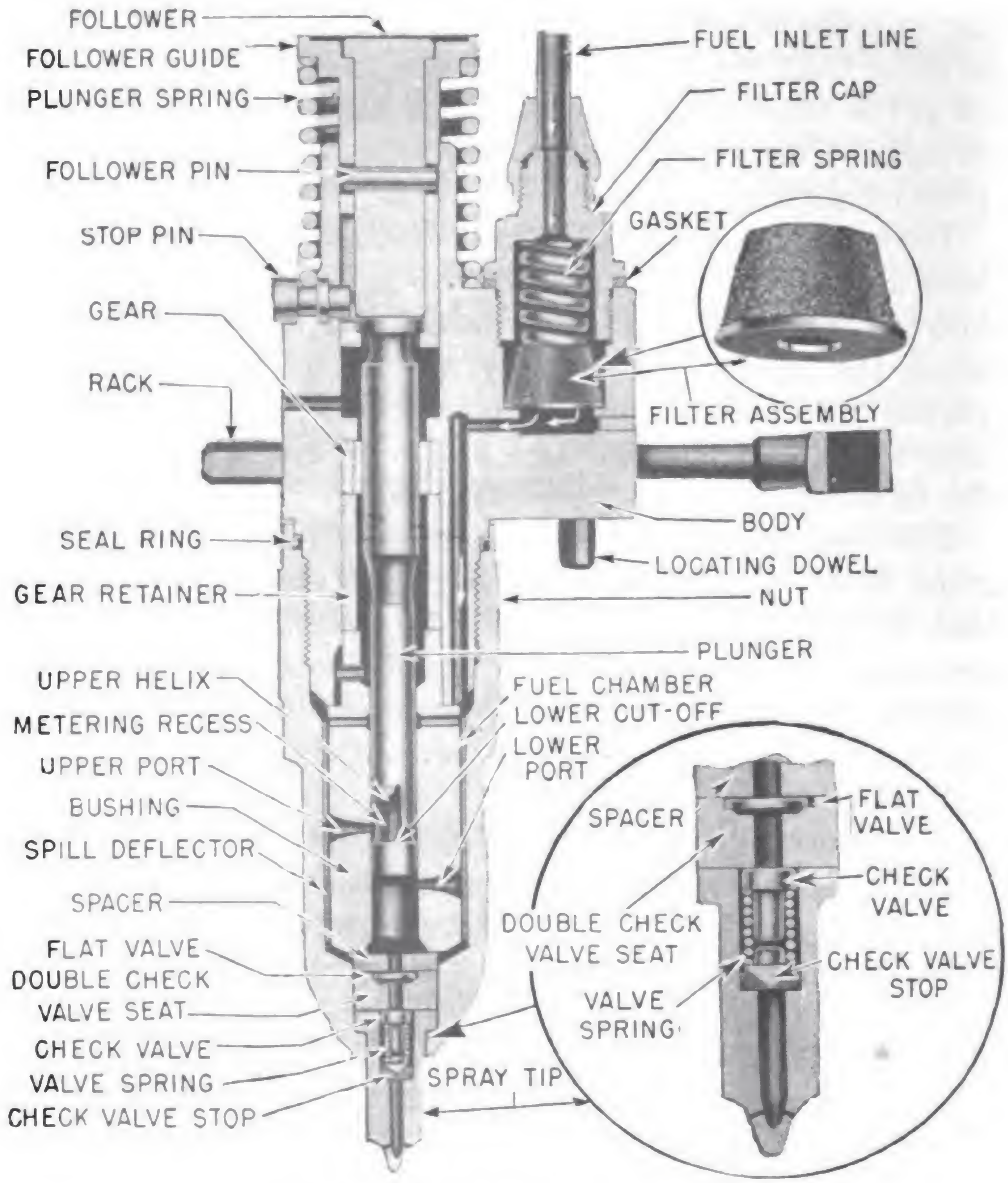


Figure 6–16.—Unit injector assembly.

which fits inside the FOLLOWER GUIDE, to which the follower is secured by the FOLLOWER PIN. The PLUNGER is held between the bottom of the follower and the land at the bottom of the follower guide. The plunger assembly is moved downward by the rocker arm which bears against the top of the follower. When the plunger assembly is pushed down by the rocker arm, the PLUNGER SPRING is compressed. The spring pushes the plunger assembly up again as the rocker arm moves upward.

The plunger forces the fuel oil into the cylinder at the proper time in the piston cycle. Fuel enters the projecting side portion of the body through a FILTER ASSEMBLY, consisting of a filter held in place by a filter spring, as shown in figure 6–16. (The oil must pass through this filter before going through the injector passages; notice the white arrows in fig. 6–16.) The filtered oil goes down through drilled passages in the injector body to the FUEL CHAMBER surrounding the bushing. From the fuel chamber, the oil gets to the space below the plunger by way of the UPPER PORT, METERING RECESS, and drilled passages in the plunger itself.

With oil under the plunger, what happens when the rocker arm shoves the plunger down? For a part of the stroke, the upper and lower ports will be closed, and the oil cannot escape. Therefore, it is placed under a sufficiently high pressure so that it is forced past the

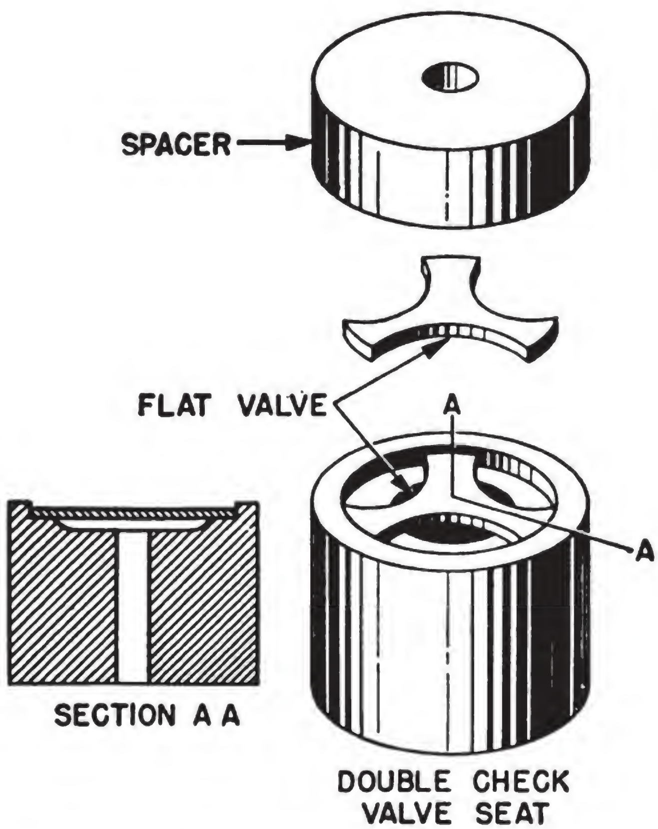


Figure 6–17.—Flat valve assembly in unit injector.

FLAT VALVE, and out through the small holes in the SPRAY TIP.

The assembly and structure of the flat valve is shown in figure 6–17. This valve is a three-pronged piece of metal which fits into a depression in the upper surface of the double check valve seat. When the plunger drives the oil downward under high pressure, the oil passes around the indented parts of the flat valve, and through the central channel in the double check valve seat.

As soon as the plunger pressure is removed, the check valve spring (fig. 6–16) slams the check valve shut against the lower surface of the double check valve seat, and injection ends abruptly. If the check valve fails to close for some reason, the high cylinder pressure will tend to drive the cylinder gases up through the injector. In this case, the flat valve is driven up against the spacer, acting as a second check valve.

The principle of injecting and metering, almost identical in all GM models, is similar to that of the Bosch pumps (discussed earlier in the chapter). Figure 6–18 illustrates the principle.

Distributor Injection System

The distributor system has several characteristic features of a unit injector, and is sometimes classified as such. In addition to the necessary filters, strainers, transfer pumps, and lines required in all fuel systems, the distributor system includes a metering pump, a distributor, and injectors. The metering pump controls the engine power. The amount of fuel pumped to the injectors is varied by changing the length of the plunger stroke, which is varied by changing the position of its actuating lever. The distributor transfers fuel from the pressure gear-pump to the metering pump; and then distributes the fuel to the injectors, in the proper firing order. (The injectors are mechanically operated by the engine crankshaft through push rods and rocker arms.) The high

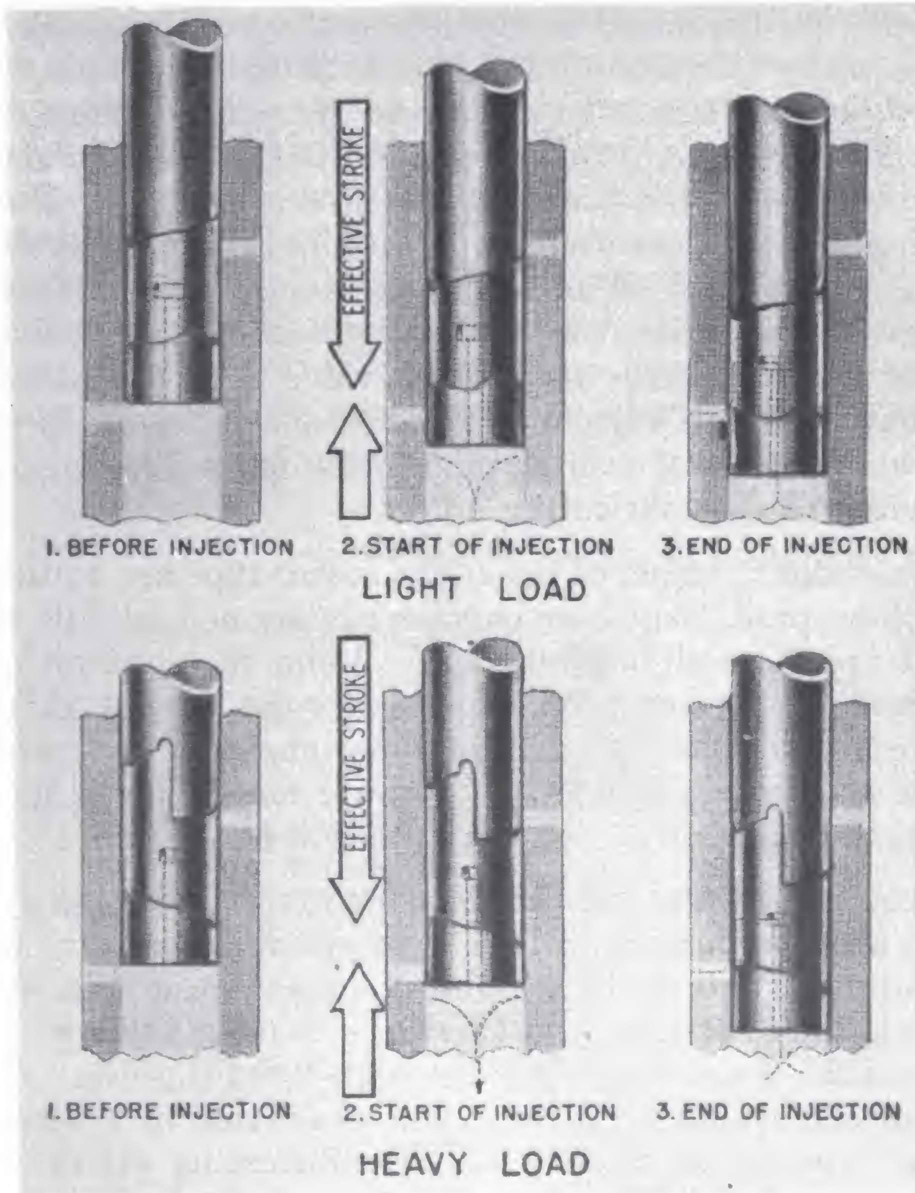


Figure 6–18.—Injection and metering principle of a unit injector.

pressure necessary for proper atomization and penetration is developed in the injector.

COMPARISON OF INJECTION SYSTEMS

Any type of injection system has definite advantages and disadvantages when compared with systems of other types. For example, the unit-injector system has short fuel lines as compared with the long lines of other systems. Greater fluctuations in pressure, or pressure

waves, are developed in systems with long lines. Pressure waves influence fuel discharge and atomization, and may produce vibration which, in turn, may cause mechanical troubles. The short fuel lines of unit-injector systems reduce the possibility of pressure waves. However, the high pressure created in a unit-injector system is a disadvantage because such pressures result in faster wear of the spray nozzles and the necessity of dismantling a considerable part of the valve gear in order to remove one unit injector. Another disadvantage is the greater chance of fuel leaks into the engine pump, and dilution of the lubricating oil.

Injection systems of the common-rail type are suitable for low-speed, large-bore engines but are not suitable for high-speed, small-bore engines. While the common-rail system provides adequate control over the amount of fuel injected into the cylinders of large engines, the system does not provide sufficiently accurate control for it to be used in engines with higher speed and smaller bore.

The low pressure of the distributor-type injection system is advantageous in that high pressure lines are not required in this system. One disadvantage of this system is the relatively large inertia of moving parts which makes the system unsuitable for high-speed engines. Another disadvantage, more or less eliminated in the new-type injector, is dilution of the lubricating oil in the engine crankcase which resulted from the leakage of fuel oil up to and beyond the plunger stem.

INJECTION NOZZLES

There are two general types of injection nozzles: the OPEN and the CLOSED types. The open type usually is a simple spray nozzle with a check valve which prevents the high-pressure gases in the engine cylinder from passing to the pump. Although the open-type nozzle is simple, it does not give proper atomization; therefore, it is not generally used. The closed-type nozzle is used more

commonly. There are two main classifications of closed-type nozzles: the PINTLE- and the HOLE-type nozzles.

A typical nozzle is illustrated in the cutaway sectional view in figure 6–19. This is a Bosch injector showing details of the nozzle holder and hole-type nozzle. The high-pressure oil from the injection pump enters the NOZZLE HOLDER BODY through an EDGE STRAINER. From the strainer the oil goes through a drilled FUEL PASSAGE which extends to the bottom of the nozzle holder body. The NOZZLE, with its SPRAY TIP, is held against the bottom

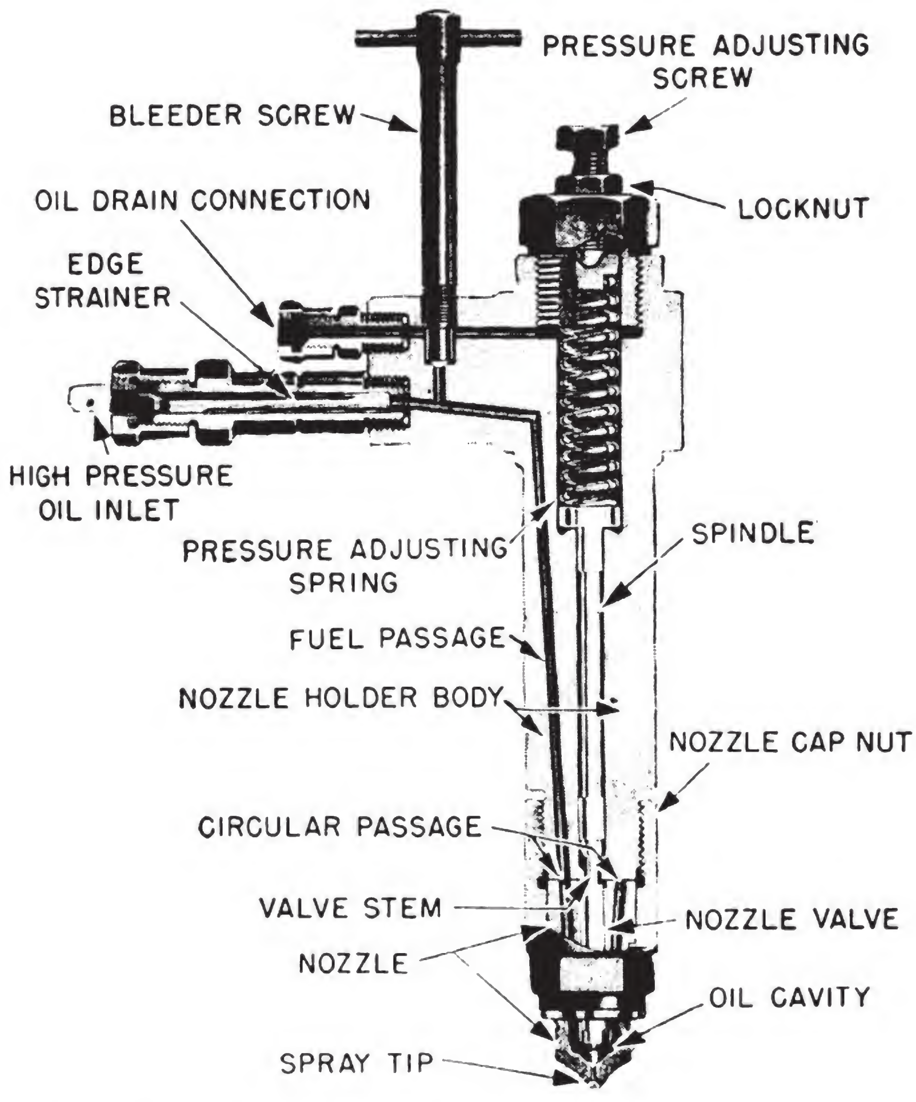


Figure 6–19.—Sectional view of Bosch injection nozzle assembly.

of the nozzle holder by the CAP NUT. A groove in the top of the nozzle forms a CIRCULAR PASSAGE for the fuel oil between the nozzle and holder.

Several vertical ducts carry the oil from the circular passage to the OIL CAVITY, near the bottom of the nozzle. The NOZZLE VALVE cuts in sharply to a narrower diameter in the oil cavity. This is important because it provides a surface against which the high-pressure oil, in the oil cavity, can act to raise the valve from its seat in the SPRAY TIP. When the valve is raised from its seat, the oil sprays out to the combustion chamber through a ring of small holes.

The valve has a narrow STEM which projects into the central bore of the nozzle holder where it bears against the bottom of the SPINDLE. The spindle is held down by the PRESSURE ADJUSTING SPRING. Whenever the upward force of the high-pressure oil acting on the needle valve exceeds the downward force of the spring, the valve can rise. The moment the spring force is greater, the valve will snap back to its seat. The spring tension is regulated by means of a pressure adjusting screw which is held by a LOCKNUT.

In spite of the close lapped fit of the valve, some oil leaks past the valve and rises through the central bore of the nozzle holder. This oil lubricates the moving parts of the injector and then drains off through the OIL DRAIN CONNECTION to a drip tank. A BLEEDER SCREW can be opened to allow the inlet oil to bypass the nozzle and go directly to the oil drain. This bypass is used to test whether an injector is at fault when the cylinder is misfiring. With the engine running, open the bleeder screw on one injector at a time. When you find an injector in which bypassing the nozzle has little or no effect on the engine performance, you have the injector that is at fault.

The two basic types of nozzles (pintle and hole), which are supplied by the Bosch company, represent essentially all other nozzle makes as well. Figure 6–20, showing the two nozzle types, illustrates just the nozzles which could

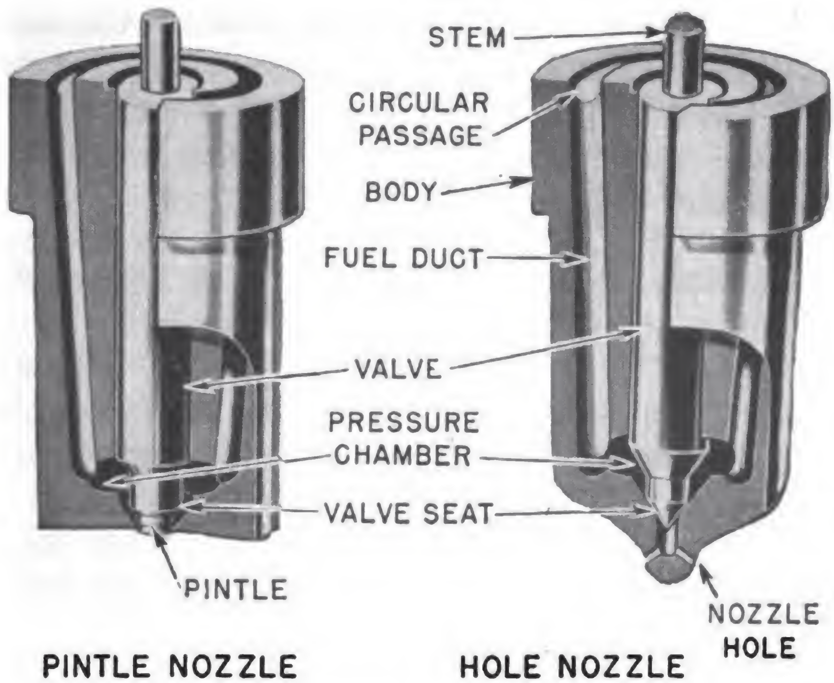


Figure 6–20.—Pintle- and hole-type nozzles.

be secured to the bottom of the nozzle holder by the nozzle cap nut (fig. 6–19).

When looking at the pintle and hole nozzles, they appear identical. The only differences are in the bottom ends of the nozzle valves and in the spray tip. (Notice the circular oil passage around the top of each nozzle.) The PINTLE NOZZLE has a flat bottom surface with a central hole. The lower end of the nozzle valve is a pin-like extension (pintle) which goes through the hole when the valve is seated. When the oil pressure raises the valve from its seat, a ring orifice is formed around the pintle, and the oil sprays out in a hollow cone. The pintle is usually a little larger at its bottom end so that the oil can spray outward. The working of the pintle through the nozzle hole helps to keep the hole free of carbon. Pintle nozzles are used in engines having precombustion chambers, divided chambers, and air or energy cells.

In the HOLE-TYPE NOZZLE, the valve ends in a cone-shaped valve seat. When the high-pressure oil raises the oil from the seat, the oil shoots down a short central chan-

nel and out through a ring of small holes in the rounded spray tip. The number of spray holes, which may range from six to eighteen, depends on the size and type of engine. Hole-type nozzles are used in engines having an open combustion chamber.

INSPECTION AND MAINTENANCE OF MECHANICAL INJECTION SYSTEMS

Since one of the requirements for trouble-free operation of a fuel system is clean fuel, the filters, strainers, tanks, transfer pumps, and lines must be maintained in accordance with prescribed instructions. Even if these parts function properly, the principal elements of the injection system—pressure pumps, injection valves, and injection nozzles—are subject to several troubles. This section covers general information concerning maintenance and repair of fuel injection pumps, injectors, and nozzles. Complete details for the maintenance and repair of each of the various types of fuel systems is beyond the scope of this training course. Specific information on a particular fuel injection system can be obtained from the appropriate manufacturer's instruction book.

Fuel Injection Pumps and Injectors

Fuel injectors and fuel pumps should not be disassembled unless defective operation is indicated. Only those parts should be renewed which are found defective or worn beyond further economical use. Units should be opened up only to the extent necessary to effect repairs. The manufacturer's instructions for servicing and adjusting these parts should be strictly adhered to. In addition, absolute cleanliness is of paramount importance.

When working with fuel injection pumps and injectors, you must remember the differences which may exist between the various systems. Maintenance and repair information applicable, in general, to all systems, as well as information on specific types of systems, is given in this section.

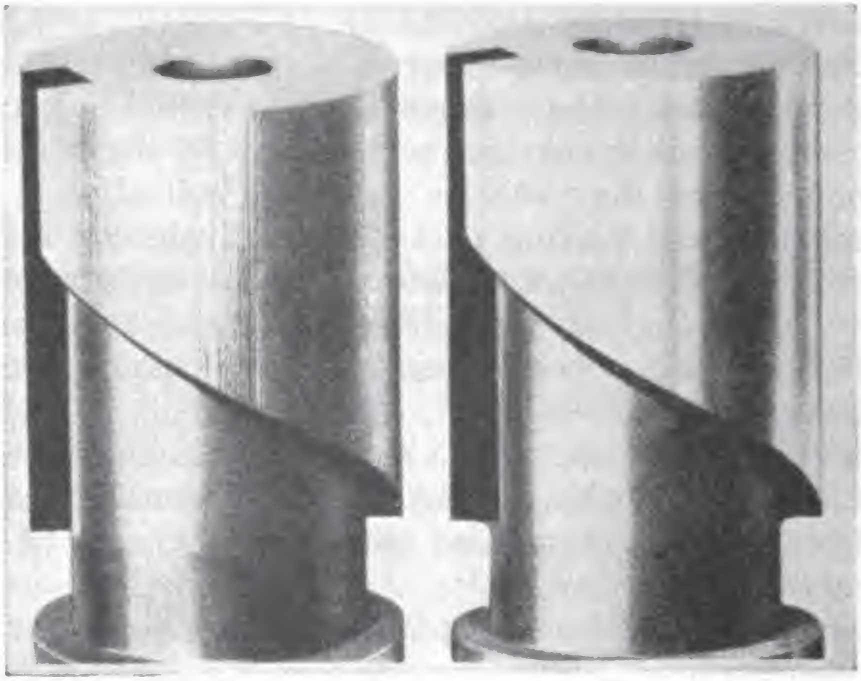
DAMAGED PLUNGER AND BARREL, OR BUSHING ASSEMBLY. —Damage to the plunger-barrel assembly of a fuel pressure pump or to the plunger-barrel assembly of a unit injector generally requires replacement of the parts. A damaged part may not be replaced individually. A plunger and its mating part (barrel, bushing, or bore) must be installed as a complete assembly. In some cases, slight abrasions may be removed from lapped surfaces by methods prescribed in fuel injection equipment maintenance manuals.

In the plunger and barrel assembly of a high-pressure pump and in the plunger and bushing assembly of a unit injector, the symptoms and causes of damage are relatively the same.

Damaged or worn plungers, or barrels, cause erratic engine operation. Symptoms of damage vary widely and may include: failure of the engine to develop full power; low exhaust temperature; low firing pressure for the affected cylinder; difficulty in balancing (calibrating) the pumps or injectors; and failure of one or more cylinders of the engine, to fire. Faulty operation of an injector unit can be determined by testing the unit on a test stand. However, there is only one way to find the cause of the trouble; the unit must be disassembled, cleaned thoroughly, and each part inspected carefully.

Cleaning of the units can be best accomplished by the use of an approved solvent. Clean Diesel fuel may be used when more effective cleaners are not available. However, a brush may be used in this case, and even then, removal of gummy deposits is difficult. During inspection, keep each plunger with its own barrel or brushing in order to avoid improper assembly.

The use of a magnifying glass during the examination of a plunger will facilitate the detection of damage. Inspection should be made for fine scratches, dull surface appearance, pin marks (usually accompanied by dark discoloration), erosion and roughness at the edge of the helix or at the end of the plunger, and cracks. An ex-



A B

Figure 6—21.—A damaged and a serviceable plunger.

ample of a badly scored Bosch plunger and erosion at the edge of the helix is illustrated in A of figure 6–21. A plunger with the lapped surface and helix edge in good condition is shown in B of figure 6–21. Surface irregularities in the region illustrated are serious because they affect metering and, consequently, engine operation.

When a barrel or bushing is examined, inspect for erosion of the ports or scoring of the lapped surfaces. Particular attention should be paid to the lapped plane surface at the end of the pump barrel. Rust or pit marks on this surface must be removed by lapping before reassembling.

Damage to the plunger of a fuel injection pump or injector may result from several factors, some of which are: entry of dirt into the equipment, careless handling while disassembled, corrosion, and improper assembly and dissembly procedures.

Dirt is responsible for practically all trouble encountered with fuel injection equipment. If the units are not properly protected against the entry of dirt, they can be

damaged beyond repair within a very short period of operation. It must be remembered that the clearances between the lapped surfaces are so small that extremely fine particles, such as dust from the atmosphere, are capable of scoring these surfaces.

An engine should never be operated unless the fuel has been properly filtered before reaching the injection equipment. Regular filters and strainers are present in all fuel systems; however, in some systems special safety filters or screens are incorporated to further reduce the possibility of the entrance of foreign matter in the fuel when it reaches the pump and injector. The location of these additional safety devices depends upon the system. In one system a screen is placed between the fuel transfer pump and the fuel distributor, while in another a filter is mounted directly on the pump. Some models of unit injectors have a filter incorporated in the body of the injector.

In addition to precautions with respect to fuel filters and strainers, it is imperative that cleanliness be stressed during the overhaul of fuel injection equipment. Care in the selection of a spotlessly clean working space is the first requisite for the protection of parts, during overhaul. (Ideally, the injector shop should be air conditioned.) All air should be thoroughly filtered before it enters the space. Benches should have smooth tops. Metal-topped benches should be covered with linoleum or other suitable material. The use of ample quantities of approved cleaning solvent, of clean fuel oil, and of compressed air to blow parts dry, will help ensure cleanliness during overhaul. Rags or waste should never be used to clean injectors, as lint particles from them may damage the injector parts.

When a unit is removed from the engine, extreme care must be taken to keep dust and dirt away from all its parts. Before any connections are loosened, all dirt should be removed from the unit, tubing, and fittings. After removal of the unit from the engine, all openings

(pump, nozzle, tubing, or injectors) should be covered with approved caps or covering.

Because many surfaces of the parts of pumps and injectors are lapped to extremely accurate finishes, it is essential that they be handled with great care. If the parts are dropped, they may be bent, nicked, dented, or otherwise ruined. The work should be done well over the center of the bench. The use of a linoleum covering will reduce casualties caused by dropping parts on the bench. Parts should not be left uncovered on the bench, but should be kept immersed in Diesel fuel until handled. Lapped surfaces should never be handled when dry, as the perspiration on your hands might cause corrosion. Before a lapped surface is handled, it should be immersed in clean Diesel fuel, and the hands rinsed in clean fuel. Since the mating parts of pumps and injectors are fitted to one another, such parts as the plunger and the barrel should be kept together to avoid interchanging. Special care must be exercised in disassembling and assembling the parts of a fuel injection system, for damage to the finely finished surfaces will necessitate replacement of the parts.

EXTERNAL LEAKAGE FROM AN INJECTION PUMP, OR AN INJECTOR.—Trouble of this nature may become sufficiently serious to cause an engine to misfire. It is of extreme importance that signs of leakage be detected as soon as possible. Leakage outside of the combustion space may be sufficiently large not only to affect engine operation but also to create a fire hazard.

Leakage from a pump may occur as a result of (1) delivery valve holder damaged or not tightened, (2) high-pressure union nut damaged or not tightened, (3) bleeder screw or gasket damaged or not tightened, and (4) cracked housing.

If the delivery valve holder is damaged, or not tightened, the threads and seating surface of the delivery valve holder should be inspected for damage. If damaged, the holder must be replaced. When the holder is

tightened, it should be run into the gasket by alternate tightening and loosening; the holder should then be tightened, but not excessively.

Since a small amount of leakage will prevent firing of the cylinder, union nuts should also be kept tight. If the high-pressure union nut is taken up tightly and still leaks, threads or seating surfaces should be checked. If the surfaces are damaged, the nut must be replaced.

If either the bleeder screw or gasket is damaged, leakage may result. Damaged parts should be replaced and the bleeder screw kept tight.

On rare occasions, pump housings become cracked. When the engine misses and everything else appears to be satisfactory, do not overlook the fact that leakage can occur within the pump casing. In that case, the pump housing should be checked for signs of leakage.

External leakage from a pump or injector can be stopped either by proper tightening of loose connections or by replacement of damaged parts. Discolored sealing surfaces are indications of leakage. If such leakage results from mild roughness of the sealing surfaces, it can often be eliminated by lapping.

PLUNGER STUCK IN BARREL, OR BUSHING.—This trouble is evidenced when the cylinder served by the stuck plunger fails to fire. Misfiring may be intermittent if the plunger sticks and releases at intervals. Upon disassembly, it may be difficult to remove the plunger. In some cases, the plunger may stick when the pump or injector is assembled, but will work smoothly when the unit is disassembled. In other cases, after the plunger barrel assembly is removed and the plunger replaced in the barrel, it may be difficult to remove the plunger from the barrel after the assembly has been out of the pump for a short time. This is particularly true when the plunger and mating part are stored under conditions that cause corrosion, or when parts are mishandled after removal.

A unit injector may be checked, after removal from the engine, by performing the binding plunger test. This

test is performed by depressing the plunger, either by hand or by using the "popping" fixture of a test stand, and noting the return action of the plunger. The plunger should return with a definite snap action. This test should be performed at three successive rack settings. Sluggish return action indicates a sticky plunger.

A sticking plunger may be caused by dirt, gummy deposits in the unit, or distortion of the plunger and adjacent part.

The movement of a plunger may be restricted or entirely prevented by small particles of dirt which may lodge between the plunger and its mating surface. Lacquer-like deposits from fuel, will also interfere with the movement of the plunger.

Because of the extremely close clearances between the plunger and mating surfaces, a slight distortion of either will cause binding. Distortion may result from dropping or striking the plunger and mating part. In some cases, improper assembly will result in distortion. Great care must be taken when handling the parts of a pump or injector.

Stuck plungers in fuel pumps or injectors should be freed. A little cleaning may eliminate the need for making a replacement. Soak the plunger and barrel or bushing assembly in an approved cleaning fluid. The assembly should be soaked overnight, or longer if necessary. However, cleaning fluids approved for this purpose will immediately soften any paint or enamel with which they come in contact, and begin to remove it; these fluids will also damage rubber gaskets.

The specific procedures for cleaning fuel injection equipment, although similar, vary to some degree, depending upon the unit involved and the manufacturer. The following brief description of the procedures for equipment made by three different manufacturers emphasizes some of the similarities and variations, and further emphasizes the need for following the appropriate manufacturer's instruction manual.

If the plunger of a Bosch fuel injection pump can be loosened by the above-mentioned cleaning procedure, but does not slide freely in the barrel, both the plunger and barrel should be further cleaned with an approved cleaning fluid rinsed in clean fuel oil, and blown dry with compressed air. A small quantity of mutton tallow should then be placed on the plunger. Working the plunger back and forth, and rotating it in the barrel should remove any gummy deposits. Instructions for fuel injection equipment emphasize that such items as hard or sharp tools should never be used in the cleaning of pumps.

Freeing the sticking plunger in a GM unit injector is done in much the same manner as in a Bosch pump.

Stains on plungers of GM unit injectors may be removed by the use of a limited quantity of jewelers' rouge on a piece of soft tissue paper, as shown in figure 6–22. It is important to remember that the plunger should not be lapped to the bushing with any abrasive, including jewelers' rouge. After a plunger has been cleaned with jewelers' rouge, it must be cleaned thoroughly with Diesel

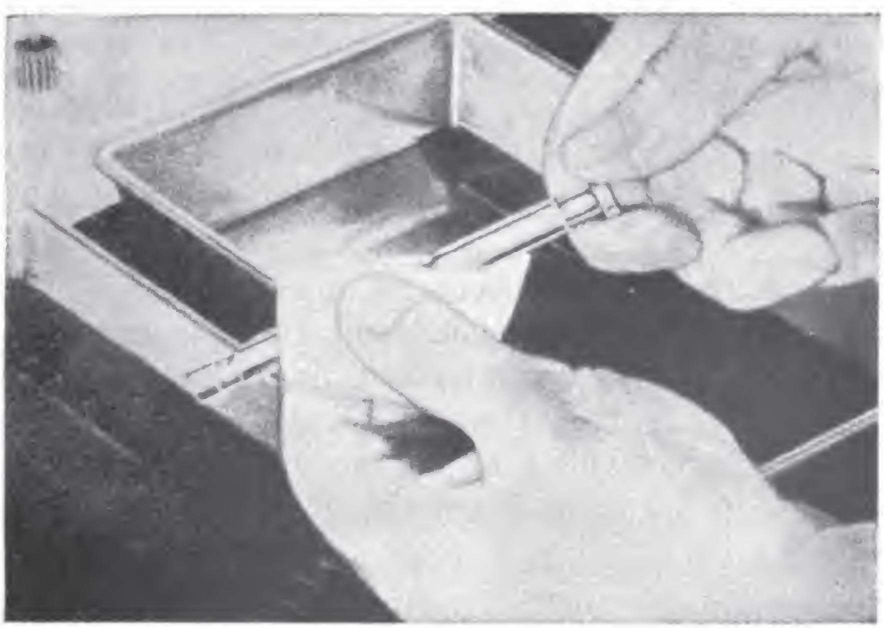


Figure 6–22.—Cleaning an injector plunger with tissue.

fuel before being placed in the bushing. If, after repeated cleanings, the plunger still does not slide freely, it is probable that either the plunger or bushing is distorted.

When the plunger in an Ex-Cell-O fuel injection pump sticks, you can usually free it by placing a small amount of mutton tallow on the plunger, then working it back and forth with a rotation motion. If this does not eliminate the trouble, repeat the above procedure, using a small amount of jewelers' rouge. If jewelers' rouge is not available, satisfactory results may be obtained by using a small amount of talcum powder mixed with a drop or two of fuel oil. Nothing coarser than talcum powder should be used when lapping the plunger and cylinder bores. After lapping the plunger and bore, wash the parts, with a suitable solvent, free of all traces of the rouge or talcum powder, and again check the plunger in the bore. In some cases, it may be necessary to repeat this procedure several times before satisfactory results are obtained.

Basically, the principal difference in the cleaning procedures for these units of equipment is in the use of abrasives. If recommended cleaning procedures for these units fail to loosen the plunger so that it will slide freely, the plunger and its mating part will have to be replaced.

BROKEN PLUNGER SPRING. The usual symptoms of pump or injector failure appear when the spring breaks and fails to return the plunger after injection has occurred.

Plunger spring failure can be largely avoided by careful inspection of, and replacement (if necessary) of the spring, each time an injection pump or assembly is disassembled. Information relative to the inspection, handling, and cleaning of engine valve springs is also applicable to the plunger springs of injection pumps and injectors.

Broken plunger springs must be replaced. In addition, a spring should be replaced when there is evidence of

cracking, chipping, nicking, or excessive wear, or when the condition of the spring is doubtful.

CONTROL RACK STICKING OR JAMMED.—If an engine is to operate satisfactorily, the fuel control rack must be completely free. Since the rack controls the quantity of fuel injected per stroke, any resistance to motion will result in governing difficulties. When this occurs, the engine speed may fluctuate (decreasing as the engine is loaded, racing as the load is removed), or the engine may hunt (continuously, or only when the load is changed). If the rack becomes jammed, it may be impossible to control engine speed with the throttle. In some cases, an engine may even resist securing efforts under such conditions. Obviously, a sticking control rack can be a serious difficulty, especially in an emergency. Therefore, every effort should be made to prevent its occurrence. The best way to check for a sticking rack is to disconnect the linkage to the governor and attempt to move the rack manually. When all springs and linkages are disconnected, there should be no resistance to movement of the rack.

A fuel control rack may stick or jam as a result of a stuck plunger, dirt in the rack mechanism, a damaged rack or gear, or improper assembly. When jamming or sticking occurs, it is necessary to determine the cause of binding. If jamming or sticking results from damage, it will be necessary to replace the damaged parts. However, if stickiness is due to the presence of dirt, a thorough cleaning of all parts will probably correct the trouble. Figure 6–23 shows the use of a brush for cleaning and compressed air for drying a fuel control rack. Errors in reassembly and adjustment can be avoided by a careful study of the manufacturer's instructions.

IMPROPER CALIBRATION (BALANCE) OF FUEL INJECTION PUMPS OR INJECTORS. When this trouble occurs, there is a difference in the quantity of fuel injected into each of the cylinders. If some pumps or injectors deliver more fuel per stroke than others, the engine will be unbalanced;

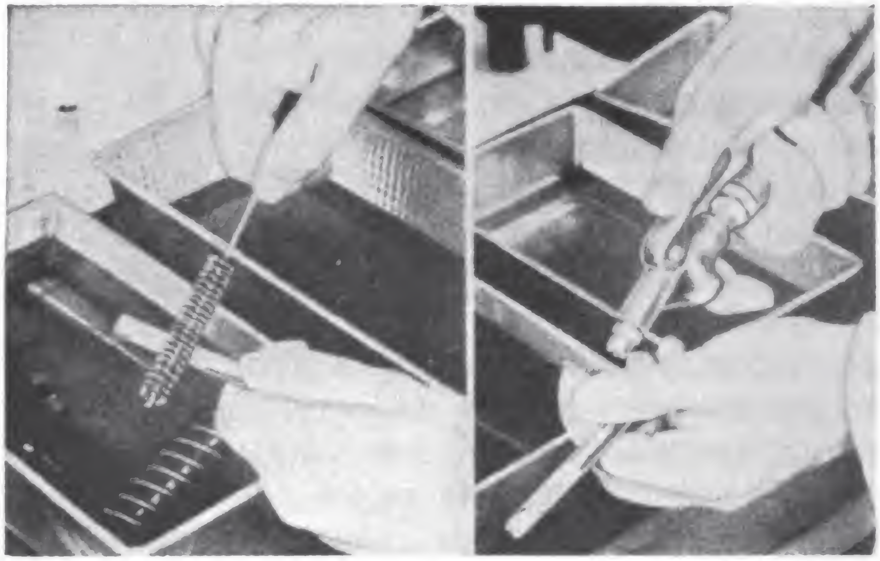


Figure 6–23.—Cleaning an injector rack.

that is, some cylinders will carry a greater load than others. This may be detected by differences in cylinder exhaust temperatures and firing pressures, and by smoky exhaust from the overloaded cylinders. Roughness in operation and engine vibration may also indicate an unbalanced condition.

It should be remembered that many other engine difficulties may cause engine symptoms identical with those due to unbalance. When unbalance is suspected, other possible troubles which should be considered are: poor condition of piston rings, mistimed injection, and mistimed or faulty engine exhaust or inlet valves.

IMPROPERLY TIMED FUEL SYSTEM.—Improper timing of a fuel system will result in uneven operation or vibration of the engine. Early timing may cause the engine to detonate and lose power. Cylinders which are timed early may show low exhaust temperatures. Late timing usually causes overheating, high exhaust temperatures, loss of power, and smoky exhaust.

In most cases, improper fuel injection timing is caused by failure to follow the manufacturer's instructions for timing. However, other causes may occur, depending upon the particular system. For example, the injection

pump of a Bosch system may get out of time because of a worn pump crankshaft, or the adjusting screw on the injector control rack of a GM system may become loose. Either of these conditions will change fuel injection timing.

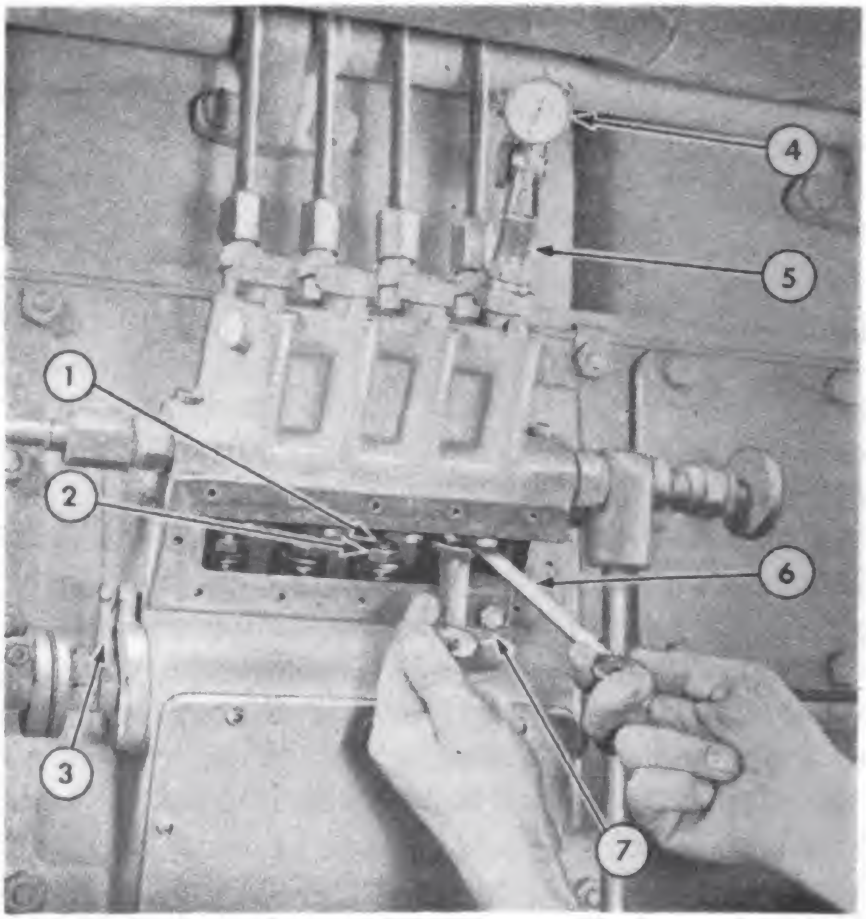
Faulty calibration and improper timing are generally due to failure to follow instructions. Instructions for the proper timing and calibration of fuel injection equipment are given in the engine instruction manual and the fuel injection equipment manual. These manuals should be consulted, and the instructions followed, whenever timing or calibration difficulties arise.

ADJUSTMENT AND TIMING OF INJECTORS.—When reassembling or installing fuel injection pumps or injectors, care must be taken to see that the timing gears (marks) are properly aligned. The section which follows deals with the adjustment and timing of Cooper-Bessemer injectors. Specific information for other type injectors can be obtained from the appropriate manufacturer's instruction books.

Two adjustments are necessary for all Cooper-Bessemer injectors; tappet clearance and valve timing adjustments. Since the amount of fuel entering the cylinder depends upon the length of time the injector valve is open, duration is of the utmost importance. This setting is adjusted by regulating the valve tappet clearance. The procedure to be used with Cooper-Bessemer injectors is as follows:

Set the eccentric (control) shaft with the pointer at "ON" position. (On older models without a pointer, the eccentric shaft is set at the 4-inch scribe marks which indicate maximum fuel position.)

Check the injector units, one at a time, for duration of injection. This can be accomplished by removing a valve cap, and installing an indicator adaptor and indicator (fig. 6–24). Rotate the engine slowly, in the forward direction, until the valve begins to open; this will be indicated by movement of the indicator pointer. Note the angular position of the crankshaft as indicated by degree



1. Lock Nut
2. Push Rod
3. Pointer at Fuel "On"
4. Dial Indicator
5. Adapter
6. Tappet Wrench
7. Injector Tappet Holder

Figure 6–24.—Adjusting the fuel injector lift.

marks on the flywheel, under the flywheel pointer (fig. 6–25). Continue to rotate the engine slowly until the valve closes, and again note the position of the flywheel. The angular displacement between the opening and closing of the valve will indicate the duration of injection. The correct duration of fuel injection on a new engine, or one on which the injector cams are not worn, is obtainable with a valve lift of 0.044 to 0.046 inches. Wearing of the cam nose has the effect of shortening duration, as illustrated in figure 6–26. To compensate for wear and

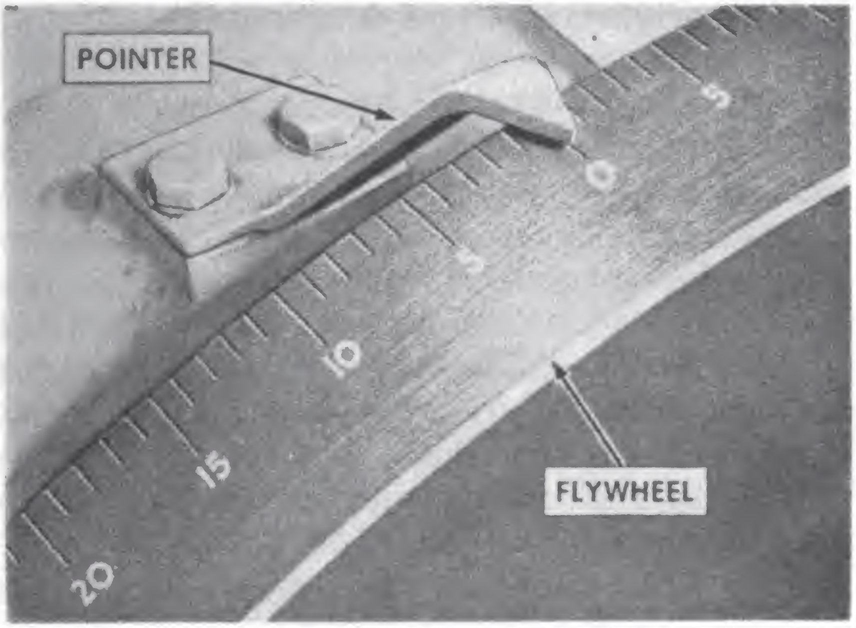


Figure 6–25.—Degree marks on the engine flywheel.

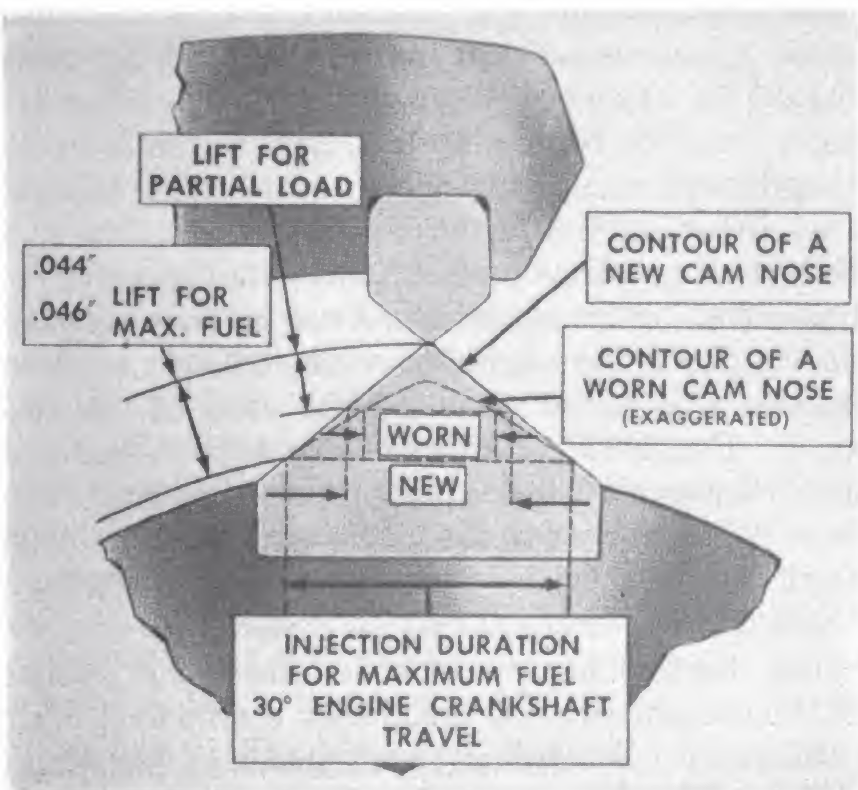


Figure 6–26.—Effect of cam wear on light engine loads.

establish the original length of duration, the tappet clearance is decreased until a 30° duration period, as measured on the flywheel, is obtained. Care must be taken to determine that a slight amount of tappet clearance is always maintained.

With worn cams, however, it is necessary to reduce the tappet clearance in order to maintain an equal rate of duration at full load. When the eccentric shaft is rotated to light load position, the valve lift is decreased until the valves actuated by the worn cams may not even be raised. This condition results in uneven idling and must be corrected by replacing the cam noses. To determine the need for replacement, check the valve lift with the indicator. A variation of more than 0.005-inch in lift between cylinders will affect light engine load operation, and indicates that wear has developed to a point where the cam noses must be replaced on injectors having the lowest lift.

If dial indicators are not provided, the duration may be measured by using a depth micrometer and determining the instant the valve opens and closes.

Another method for timing is to close the shut-off valves on all cylinders except the one to be tested. Disconnect the fuel injection line from the injector to the nozzle. Apply fuel oil pressure with a hand priming pump, or by operating the fuel pump with a lever on those engines so equipped. Turn the engine over until the injector valve opens; this will be indicated by the drop of the fuel oil pressure. Continue rotating the crankshaft and operating the fuel pump until the fuel oil pressure starts to rise, which will indicate that the valve has closed. Angular travel of the flywheel between opening and closing will constitute the duration.

Timing the fuel injector for the start of injection requires the valve to open at the proper crankshaft position. This differs with the engine, speed, grade of fuel, and type of service. Therefore, you should consult the engine instruction manual for timing. (In addition, the final

setting may depend on the operation of the engine and the grade of fuel oil employed.)

Check the beginning of valve lift with a dial indicator or the above-mentioned fuel pressure method. See that the fuel control shaft is at fuel "ON" position. If the timing is not correct, loosen the set screws in the fuel camshaft, and rotate the camshaft in the direction of rotation to a point where the valve begins to open. Tighten the gear on the camshaft and recheck start of injection by backing up on the flywheel past start of injection, and then barring in the direction of rotation. The timing must always be adjusted with the shaft rotating in the "AHEAD" direction so that any slack in the timing chain or gears will be taken up.

On a reversible engine, shift the camshaft to "ASTERN" position and check the timing for that rotation. It is impossible to change the astern timing without altering the ahead timing. It is better to favor the "AHEAD" rotation because the engine operates in that direction most of the time, and on propeller installations the astern rotation does not load the engine as much as ahead rotation.

Spray Nozzles and Tips

Even though nozzles and tips are designed in many variations, all function to direct the fuel into the cylinder in such a pattern as to bring about the most efficient combustion. The slightest defect in the spray nozzles and tips will affect engine operation. Whether in the spray tip of a unit injector, or in a separate spray nozzle attached by a high-pressure line to a pump, the troubles encountered, as well as the causes, are relatively the same. As in the case of fuel pressure pumps and injectors, this discussion cannot be all-inclusive. Only troubles more or less common to most fuel injection systems are discussed in the sections which follow.

INCORRECT NOZZLE OPENING OR INJECTOR POP PRESSURE.—This type of trouble will definitely influence engine

efficiency and performance. The exact effect will vary according to the type of combustion space served. When the opening pressure is greater than the specified value, it tends to decrease the amount of fuel injected, and also tends to retard the start of injection. A low nozzle opening pressure decreases the atomization of the fuel at low speeds, and in extreme cases will cause dribble. It also tends to increase the amount of fuel injected, which will cause a smoky exhaust from the engine cylinder affected. The best protection against such trouble is a periodic check, with an appropriate tester, of the nozzle or injector. One type of test stand is shown in figure 6–27. Test stands will vary to a degree, depending upon the manufacturer. However, all test stands operate on the same

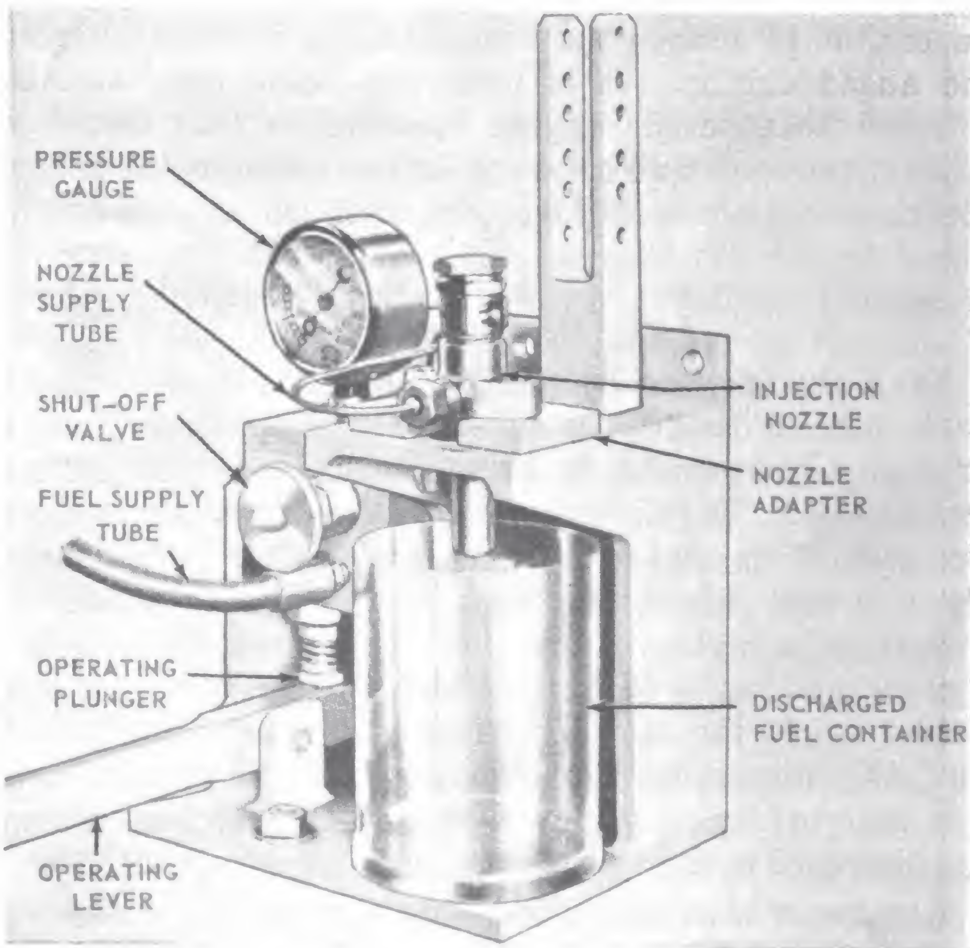


Figure 6–27.—Universal test stand.

principle. Although the type of test stand illustrated is intended primarily for activities doing considerable nozzle and injector reconditioning work, modifications of this equipment can be found on many vessels using fuel injection equipment.

Tests that may be performed on this type of fixture are: spray tip orifice test, valve opening pressure test, and holding pressure test. Complete details on test procedures can be obtained from the appropriate fuel injection equipment maintenance manual.

When a tester is used, remember that the penetrating power of the fuel oil spray is sufficient to drive oil through your skin. Since this can cause blood poisoning, all parts of the body must be kept out of line of the fuel spray.

When the opening pressure of a nozzle is too high, the cause will depend upon the fuel system involved. For example, if a Bosch nozzle opening pressure is too high, or if the nozzle fails to open, the pressure spring may be improperly adjusted, the nozzle valve may be stuck in the nozzle body, or the nozzle orifices may be clogged. On the other hand, too high an opening pressure in the Ex-Cell-O injection nozzle may be caused by troubles similar to the latter two just mentioned, but there is no provision for adjusting the pressure spring. This is also true of the GM unit injector. Therefore, if the opening pressure of an Ex-Cell-O nozzle is incorrect because of the spring, the nozzle must be disassembled and a new spring installed. For this reason, it is advisable to be familiar with the equipment with which you are working, and follow the appropriate injection system maintenance manual.

If improper pressure is suspected, unit injectors should be tested. However, remember that injectors equipped with needle valve assemblies cannot be tested for opening pressure without special equipment. Attempts to do so will result in severe damage to the test equipment and injector. Complete instructions for testing this type of injector can be obtained from the unit injector maintenance manual.

When it is possible to build up a pressure considerably higher than the pop pressure prescribed for a unit injector, it is likely that this condition is due to improper assembly of injector parts. In certain models of unit injectors, it is possible to reverse one of the check valves. This will cause the check valve to seat when the fuel tends to flow from the injector to the engine.

Too low a pop pressure for a unit injector may be due to a weak valve spring or dirty sealing surfaces. In nozzles where adjustments are possible, a low opening pressure may result from a broken or an improperly adjusted pressure spring.

DISTORTED SPRAY PATTERN.—The fact that the spray pattern of a nozzle or injector is distorted may be indicated by such symptoms as a low firing pressure, loss of power, smoky exhaust, or local deposits of carbon within the combustion space. Nozzles and injector spray tips are so designed that combustion should start before any appreciable quantity of fuel has struck the relatively cold surfaces of the combustion space. Orifices are drilled to take advantage of air currents in creating turbulence. For efficient combustion, the spray pattern must not become distorted. The spray pattern can be checked with a tester similar to one of those illustrated in figure 6–27 and 6–28. However, throttling-type pintle nozzles are difficult to test with a hand tester, because of the high number of strokes per minute required to produce a satisfactory spray pattern. A motor-driven test stand is highly desirable when testing a nozzle of this type.

Distortion of a spray pattern may result from eroded valves, eroded or clogged orifices, or a broken pintle. Erosion of orifices or valves generally results when filtration of centrifuging of the fuel is inadequate. A clogged orifice, or injector spray hole, will prevent mixing of the fuel charge with the available air in the cylinder, and will result in a drop in the power output of that cylinder, causing other cylinders to be overloaded. Nozzles and injectors must be inspected carefully, when removed from

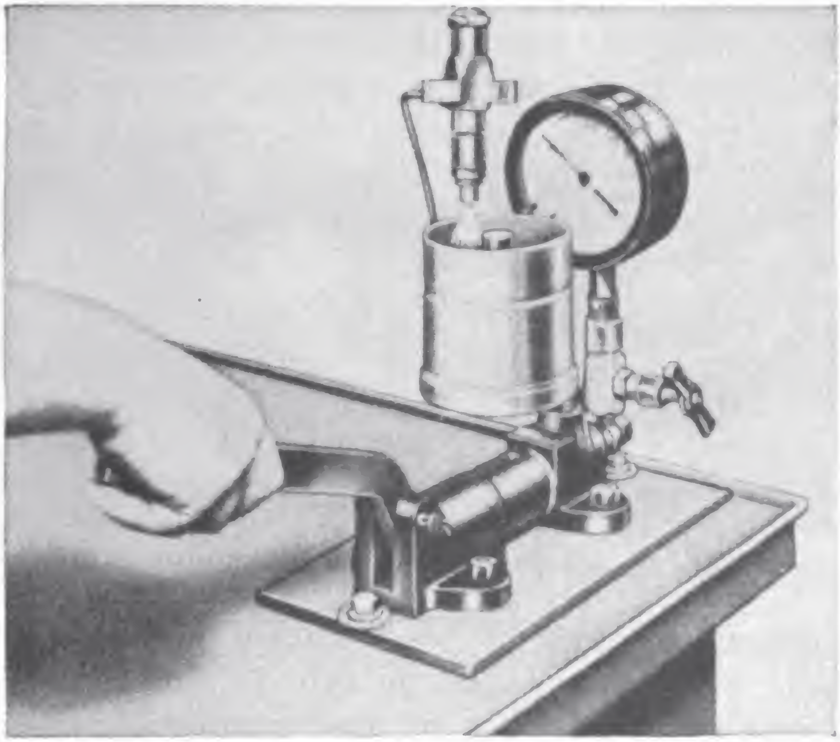


Figure 6–28.—Testing a spray nozzle.

the engine, to determine if any of the orifices are clogged.

When pintle-type nozzles are handled, they should receive extra care to avoid damaging that portion of the nozzle valve which protrudes below the bottom of the nozzle body. When carbon is being removed from the nozzle body, it is possible to inadvertently damage the pintle. In addition, pintles may be broken off by striking or dropping the nozzle and holder on a hard surface.

Clogged or eroded orifices should be cleaned as shown in figure 6–29. The cleaning wire should be held at the same angle as the drilled orifice; otherwise, the orifice may be damaged or the cleaning wire may break as it passes through the opening. If, after the nozzle is thoroughly cleaned, the spray is still distorted, it is probable that erosion of the parts has occurred. Such a condition requires replacement of the nozzle.

LEAKY NOZZLES AND INJECTOR SPRAY TIPS.—Dribbling from a nozzle or an injector may result in smoky opera-

Figure 6–29.—Cleaning nozzle orifices.

tion, detonation, loss of power, crankcase dilution, or excessive carbon formation on cylinder injection equipment and other surfaces of the combustion chamber. When a nozzle or injector spray tip is suspected of leakage, it should be checked on the appropriate tester.

Dribbling of nozzles may be due to a damaged valve or valve body seat, a dirty nozzle, a broken pressure adjusting spring or screw, or a nozzle valve stuck in the nozzle body. Leakage from a spray tip or an injector may be due to damaged sealing surfaces or broken valve springs.

In many cases, leaking or dribbling nozzles may be repaired and placed back in service. If a nozzle is leaking, it should first be soaked overnight in a suitable solvent, and the accumulated deposits then removed with brass tools, or tools of softer metal. The nozzle body should be secured in an appropriate holding device, and the nozzle valve coated with clean mutton tallow and rotated into the valve body; this procedure will usually remove the surface deposits responsible for leakage.

If this procedure does not stop the leakage, the lapping process, explained in detail in the fuel injection equipment maintenance manual, may be necessary. This is a precision operation, and unless all the precautions listed in the manual are followed, the nozzle may be ruined.

Any nozzle must be replaced if it is cracked, excessively corroded, or so badly stuck that valve removal is impossible. Defective nozzles are generally shipped to a reconditioning center. If it becomes necessary for you to assemble a nozzle, see that all parts are inserted in their proper positions. After assembly, the unit must be tested to determine whether it performs as specified in the instruction manual. If the unit does not meet the specifications, it should be replaced.

Bleeding Air Out of Fuel System

Air in the fuel system is one possible trouble which may prevent an engine from starting. Even if starting is possible, air in the fuel system will cause the engine to miss and knock, and perhaps stall.

When an engine fails to operate, stalls, misfires, or knocks, there may be air in the high-pressure pumps and fuel lines. If air is present in the system, compression and expansion of such air may take place without the injection valves opening.

The presence of air in a fuel system can be determined by bleeding a small amount of fuel from the top of the fuel filter, or by slightly loosening the bleeder screw or plug. If the fuel appears quite cloudy, it is likely that there are small bubbles of air in the fuel.

In working with fuel systems, you should remember that if air is entering a fuel line, the pressure within the fuel line must be lower than atmospheric pressure. The smallest of holes in the transfer pump suction piping will permit air to flow into the system in quantities sufficient to air bind the high-pressure pumps. Carefully inspect all fittings in the suction piping. A loose fitting or a damaged thread condition will allow air to enter the system. On installations where flanged connections are used, the condition of the gaskets should be checked. Tubing, especially copper, should be inspected carefully for cracks which may result from constant vibration.

If you let an engine run out of fuel, trouble can be ex-

pected from air which enters the fuel system. If considerable quantity of air exists in the filter, a quick method of purging the system of air is to remove the filling plugs on top of the filter and pour in clean fuel oil until all air is displaced. Any air remaining in the system can then be removed by using the hand-priming pump.

Cranking the engine for a period not exceeding the specified cranking period will remove any small amount of air in the system; but if the engine does not start during this interval, cranking it further will only reduce or deplete the starting air supply.

On most installations, the hand-operated transfer pump may be used to remove air from the fuel system. In general, the procedure is to remove air progressively from all parts of the system, starting with the suction line of the transfer pump and proceeding to the injection valves. However, the procedure varies slightly in different systems, depending on construction.

For example, in the fuel system illustrated in figure 6–30 the line is opened between the pump and strainers. The pump is operated until all air is removed and only clear fuel flows from the line. Then the line is closed and the same procedure is repeated at such points in the system as between the strainers and the filters, between the filters and the high-pressure pumps, and at the overflow line connection on the high-pressure pump housing. In small high-speed Diesel engines, priming at the overflow connection may be all that is necessary. Since priming

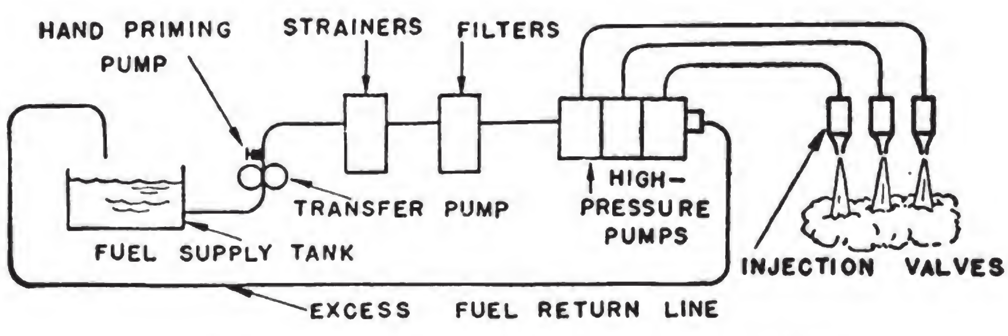


Figure 6–30.—Schematic drawing of a fuel system.

high-pressure lines is time consuming, attempt to start the engine before purging these lines. However, the engine must not be cranked for more than the specified interval of time. If the engine still fails to start, priming the high-pressure lines will be necessary. Since the procedure necessary to prime high-pressure lines varies considerably with different installations, consult, when necessary, the specific manufacturer's instruction book for the procedure.

SUMMARY

Fuel injection systems function to deliver fuel to the cylinders at the proper time and in the proper quantity, under various engine loads and speeds. The proper operation of a Diesel fuel system requires that the system must be clean, that the injection timing and balance between the cylinders must be accurate, and that the injectors and nozzles must be kept in correct adjustment.

Fuel injectors and fuel pumps should not be disassembled unless defective operation is indicated. Only those parts should be renewed which are found defective or worn beyond further economical use. Units should be opened up only to the extent necessary to effect repairs. Before proceeding with any maintenance or repair work on a fuel injection system, it is of utmost importance to consult the manufacturer's instruction book.

QUIZ

1. What is the primary function of a fuel injection system?
2. What is meant by penetration?
3. Mechanical injection systems may be subdivided into what three main groups?
4. What is the purpose of the spring-loaded bypass valve on the header of the basic common-rail injection system?
5. How is the needle valve of a basic common-rail system lifted?
6. In the basic common-rail injection system, the duration period of the needle valve opening is dependent upon what factor?
7. Why is the common-rail system not suitable for high-speed, small-bore engines?
8. What is the advantage of the modified common-rail system over the common-rail system?
9. What fuel-injection system is equipped with a supply pump, a governor, and high-pressure injection pumps built into a single assembly?
10. Compared with the Ex-Cell-O injection system, how does the operation of the plungers of the Bosch injection pump differ?
11. What mechanism is used to measure the amount of fuel to be injected at each plunger stroke of an Ex-Cell-O injection pump?
12. Which fuel-injection system combines a pump and a fuel-spray nozzle in one unit?
13. What system has short fuel lines as compared to the long fuel lines of other systems?
14. What are two main classifications of closed-type nozzles?
15. What is the only way of definitely determining whether or not a plunger-barrel assembly of an injection pump is damaged?
16. What is the principal cause of most trouble encountered with fuel injection equipment?
17. What is incorporated in some fuel injection systems to reduce the possibility of foreign matter entering the pumps and injectors?
18. When the plunger of a pump is being handled, what precaution should be taken to reduce the possibility of corrosion of the lapped surfaces?
19. If the fuel injection equipment is suspected as the source of trouble, what is probably wrong if the cylinder of an engine misfires intermittently?
20. When the plunger in an Ex-Cell-O fuel injection pump sticks, how can it generally be freed?

21. What is the best way to determine if governor difficulties are due to a sticking fuel control rack?
22. In general, what is the cause of faulty calibration and improper fuel injection timing?
23. What is the best way to ensure that the opening pressure of a nozzle or the pop pressure of an injector is correct?
24. When the valve opening pressure of an injector is being tested, what precaution must be taken for personal safety?
25. With respect to orifices or nozzles, what will generally result when filtration or centrifuging of the fuel is inadequate?
26. How can you determine if a fuel system is air bound?
27. When an excessive amount of air exists in a fuel filter, how may the system be purged of air?
28. At what point in a fuel system should you start when using a hand-operated transfer pump to remove air from the system?

CHAPTER 7

CARBURETION AND THE CARBURETOR

As an EN2, you are required to know the principles of operation of carburetors, as well as other gasoline engine units. The main parts of a gasoline engine are similar to those of a Diesel engine. The two engines differ principally in that the gasoline engine has a carburetor and a spark ignition system. In addition, the gasoline engine has a lower compression ratio than the Diesel engine.

Since flywheels, starting motors, batteries, generators, pumps, and transmissions were discussed earlier in this training course, and the principles of operation of ignition system units were explained in *Engineman 3,* NavPers 10539, this chapter will only cover carburetors. In addition, information concerning the gasoline fuel system may be obtained from either *Engineman 3,* NavPers 10539 or *Fireman,* NavPers 10520–A. The principles of operation, as well as the adjustment and maintenance of carburetors are discussed in the sections which follow.

CARBURETION AND COMBUSTION

If the fuels used in internal combustion engines were not liquid but were in the form of a gas, the problem of carburetion (supplying the proper mixture of fuel and air to the cylinder) would be fairly simple. Liquids do not burn; only the vaporized gas from a liquid will burn, and even then plenty of air must be mixed with it.

No matter what fuel an engine uses, the combustion

process is essentially the same. Combustion consists of the union of oxygen (O_2) and fuel, releasing large amounts of energy by rapid burning. The chief waste products of fuel combustion are carbon dioxide (CO_2) and water (H_2O).

Air is composed mainly of oxygen (21 percent) and nitrogen (79 percent). Since only the oxygen is used in combustion, about four-fifths of the air is unchanged by the process. Before combustion takes place, the mixture in the cylinder consists mainly of oxygen, nitrogen, and gaseous fuel; after combustion occurs, the mixture consists essentially of nitrogen, carbon dioxide, and water.

Combustion in the gasoline engine cylinder takes place at the end of the compression stroke, and is practically finished before the piston starts downward. The pressure of the expanding gases drives the piston down, delivering power to the crankshaft.

The CARBURETOR is a device for sending a fine spray of fuel into a moving stream of air on its way to the intake valves of the cylinders. This spray is swept along, vaporized, and mixed, as a gas, with the moving air. The amount of fuel sprayed into the air stream must change with different engine speeds and engine loads. In addition, the amount of fuel required is different for cold and warm engines, and special fuel adjustment is needed for rapid acceleration.

All of these varying fuel requirements are met automatically by modern carburetors. Once the engine is running, the only control the engine operator has—and the only one he needs—is a throttle valve, which he opens and closes with a simple lever arrangement. The following sections on carburetor mechanisms will help you understand the different types of carburetors you will have to operate and adjust.

THE CARBURETOR MECHANISM

The elementary parts of a carburetor are illustrated in figure 7–1. The opening through which air enters the

carburetor is called the air horn. In it, you see the CHOKE VALVE. The decrease in size of the air passage, or restriction, in the throat of the carburetor is called the VENTURI, which causes the air passing through it to do so with greater speed than it would without the restriction. The DISCHARGE NOZZLE, connected to the FLOAT CHAMBER by a fuel passage, is placed in the venturi so that the air stream will act on the liquid fuel in the nozzle. The THROTTLE VALVE is placed in the carburetor throat between the discharge nozzle and the intake manifold connecting the carburetor to the engine cylinder.

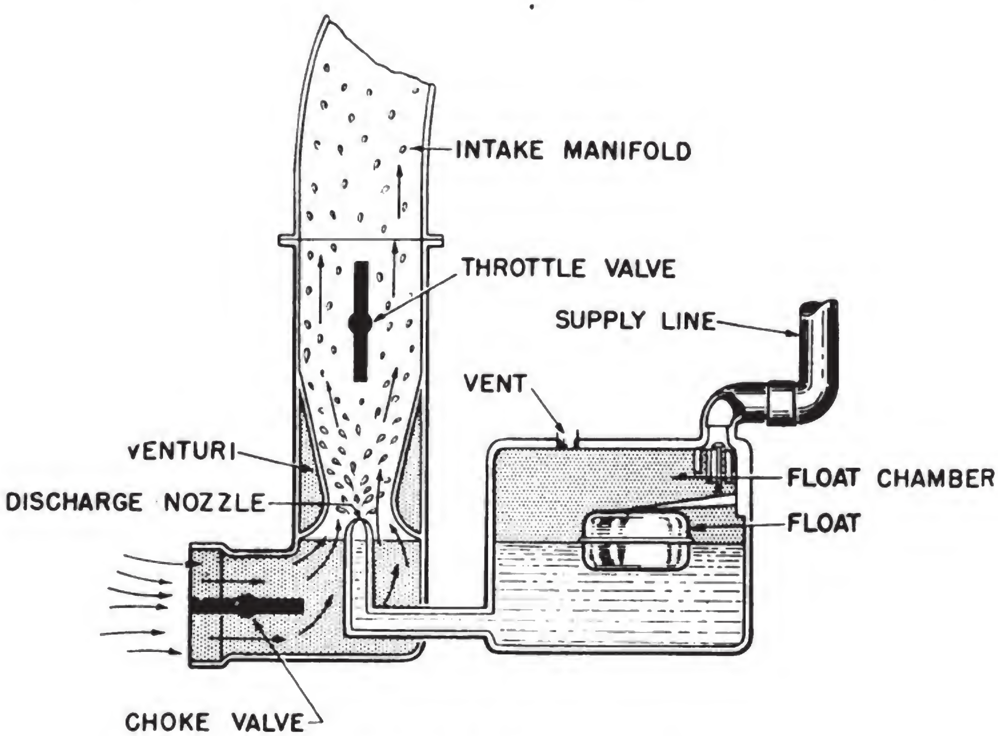


Figure 7–1.—Simple float-type carburetor.

When the piston in the cylinder moves downward on the intake stroke, it creates a partial vacuum (suction) and air enters to fill the cylinder. The only entrance provided for the air is through the carburetor. As the air rushes in, it creates a lower pressure at the tip of the discharge nozzle by action of the venturi. Since atmospheric pressure acting on the fuel in the float chamber

is greater than that at the discharge nozzle, fuel is forced from the float chamber through the nozzle and into the passing air stream. As the fuel is forced from the tip of the nozzle, it is picked up by the rapidly moving air stream and carried with it into the engine cylinder. The force of the air striking the fuel atomizes it into a fine mist, which is the first step toward VAPORIZATION and the MIXING of the air and fuel.

The choke valve and the throttle valve regulate the flow of air through the carburetor. The settings of both valves affect not only the amount of air flowing through the carburetor, but also the amount of gasoline which is carried along to the cylinder with it. However, as every car driver knows, the actual results of operating the choke valve and the throttle valve are entirely different. Refer to figure 7–1 and see what happens when these valves are opened or closed during the intake stroke; during this stroke the mixture enters the cylinder.

When the choke valve is closed and the throttle valve is opened, the air entering the carburetor will be at atmospheric pressure, while the vacuum caused by the piston down stroke will extend back through the carburetor as far as the inside of the choke valve. The result of this will be a flood of gasoline from the fuel nozzle, and a very RICH MIXTURE will be drawn into the cylinder. A "full" choke (valve completely closed) will stall an engine in a few seconds. The choke valve is used only when an extra rich mixture is required, as in cold starting.

When the choke valve is open and the throttle closed, atmospheric pressure will extend from the air inlet through the carburetor as far as the inside of the throttle valve. The vacuum extends from the cylinder back to the throttle. In this case, no air or fuel would be drawn into the cylinder and the engine is inoperative. Actually, the throttle of an engine in operation is never fully closed. Some air will always flow through the carburetor, and some fuel will be carried into the cylinder.

The throttle valve regulates the speed with which the air flows through the venturi of the carburetor. This air speed controls the amount of fuel drawn into the air stream from the fuel nozzle. The amount of fuel, in turn, governs the force developed at each combustion, and consequently regulates the speed of the engine. Under normal operating conditions, the throttle valve is the only carburetor control that is used.

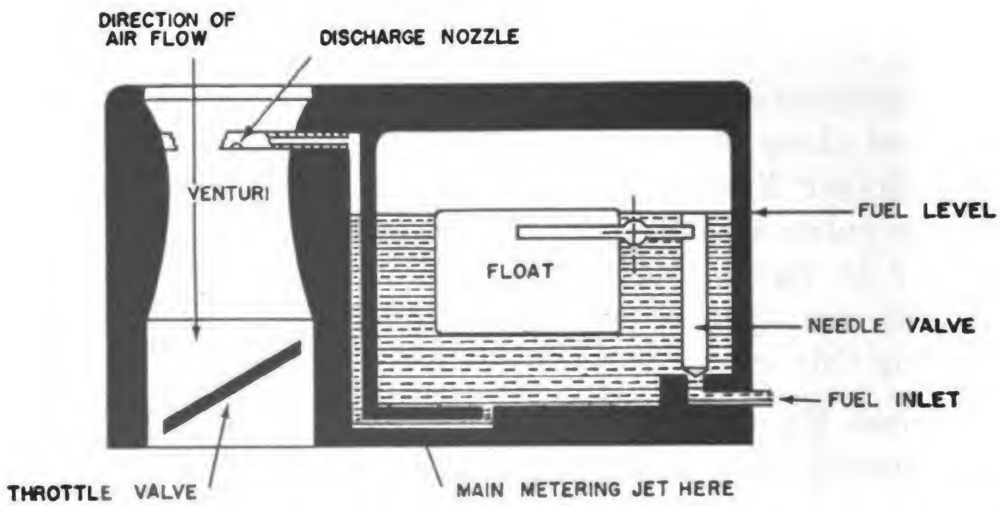


Figure 7–2.—Schematic diagram of downdraft carburetor, showing elementary principles.

Anyone who has examined the carburetors of today's high-speed gasoline engines knows that they are intricate and delicate mechanisms. Carburetors are classified as UPDRAFT or DOWNDRAFT, depending on whether they are designed for mounting below or above the intake manifold. If the carburetor is located below the intake manifold, it is called an updraft carburetor; and if located above the intake manifold, it is called a downdraft carburetor. The latter type carburetor is used on most modern installations because it reduces fire hazards, and provides better distribution to the cylinders, than the updraft carburetor. Figure 7–2 illustrates a diagrammatic sketch of a downdraft carburetor, showing the elementary principles of operation.

OPERATION OF CARBURETORS

The modern carburetor must accurately meter fuel and air, in varying percentages, in accordance with engine requirements. The amount of fuel mixed with the air must be regulated carefully, and must change with the engine's different speeds and loads.

The fuel-air mixture should be relatively rich for idling and low speeds, slightly lean for normal operating speeds, and slightly rich for high speeds or heavy loads requiring near maximum power. Special devices, or systems, are provided on modern carburetors to change the mixture automatically. There are many different designs of these devices. If you understand the general types of devices discussed in the paragraphs which follow, you will be able to learn the special details of any carburetor you work with. However, before proceeding further, it may be best for you to review the basic principles of a float-type carburetor (which is most commonly used), and the fuel induction system, discussed in *Fireman,* NavPers 10520–A.

Idling Device

While the engine is running at idling speed, under practically no load, the idling device provides the correct fuel-air mixture. When the engine is idling, the throttle valve is nearly closed (fig. 7–3). The air flows through the venturi tube so slowly that the vacuum is not great enough to draw any fuel spray from the main and cap jets. However, the velocity of the air flow is quite high past the edge of the nearly closed throttle valve. This sets up a vacuum much like a venturi does, so that the vacuum in this high-velocity stream of air is great enough to draw fuel from the idling jet. (Note that the idling jet is connected to the edge of the throttle by an idling tube, or passage.)

When the throttle is opened gradually, the air flow through the venturi will increase, and at the same time the gap between the throttle edge and the idling jet will

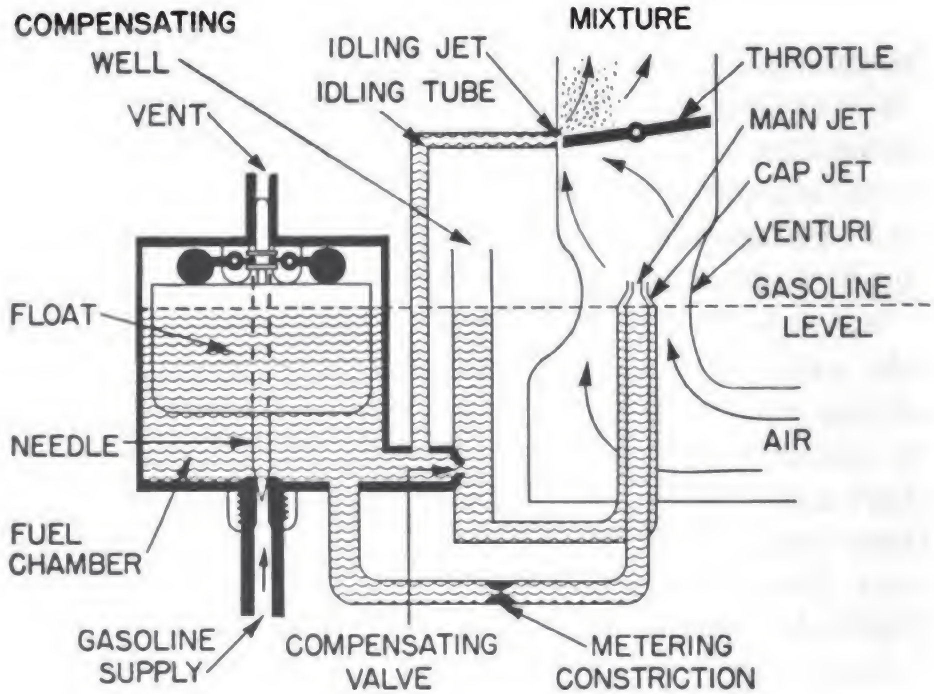


Figure 7–3.—Diagram of carburetor with engine idling.

widen. The increased air flow in the venturi reduces the pressure in the constricted throat so that gasoline rises and sprays from the main and cap jets of the double (compound) nozzle. As a result of the increased gap between the throttle plate edge and the throat wall, the idling jet no longer sprays gasoline into the air stream, and the level in the idling tube falls back to chamber level as shown in figure 7–4.

The earliest carburetors used with gasoline engines had only a single jet as the main fuel supply in the venturi. It was found, however, that the single jet did not produce a constant fuel-air ratio at all speeds. Instead, the fuel spray increased out of proportion to the air flow so that the mixture became too rich. In a modern carburetor, however, this trouble is remedied by using a compensating (CAP) jet, which is added to the compound nozzle. If you could plug up the COMPENSATING VALVE, or ORIFICE, shown in figure 7–4, there would be no supply of fuel to the cap jet. Then the main jet would produce an in-

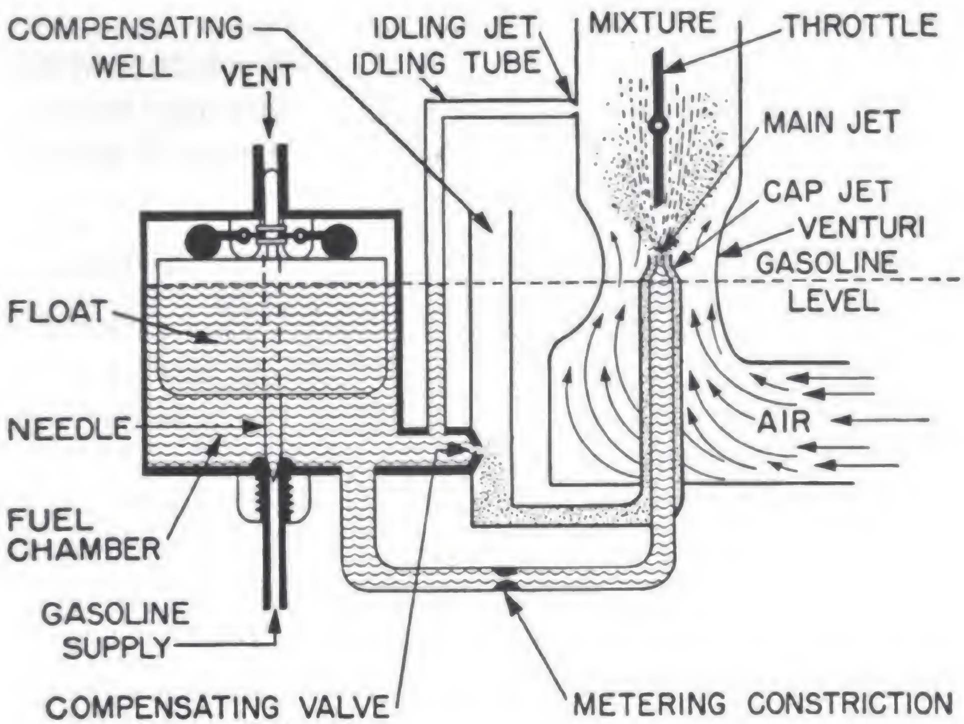


Figure 7–4.—Diagram of carburetor, at full throttle.

creasingly rich mixture, with increased throttle opening, as in a single jet carburetor.

The cap jet forms a ring around the main jet and is connected with the tube leading to the compensating well. The gasoline supply to the tube and compensating well travels through the compensating valve (orifice). This orifice allows a constant flow of gasoline under the constant pressure of the head of fuel at the chamber level. At idling speeds, when no fuel is being drawn from the cap jet, the flow from the compensating valve will stop when the fluid reaches the chamber level in the compensating well (fig. 7–4).

Notice that the compensating well is open to the atmosphere (fig. 7–3 and fig. 7–4.) Any vacuum effect which draws fuel from the cap jet faster than it is supplied with fuel through the orifice will drain the well. After that happens, a mixture of air and gasoline will be drawn through the cap jet (fig. 7–4). In other words, when the throttle is first thrown open, the cap jet will supply a rich mixture for a short time. If the engine speed remains

high, the mixture becomes quite lean. This lean mixture from the cap jet compensates for the rich mixture which comes from the main jet at high speeds; the final mixture has the desired proportions of fuel and air when it reaches the cylinders.

Accelerating Devices

When the throttle is opened suddenly, there is a rapid increase in the airflow through the carburetor, but the fuel flow does not increase immediately. Instead, the fuel flow lags behind and causes a temporarily lean mixture which, in turn, may result in erratic operation of the engine or a backfire. To prevent this condition, all modern carburetors are equipped with accelerating systems. The function of the accelerating system is to discharge an additional quantity of fuel in the carburetor air stream when the throttle is suddenly opened, thus causing a temporary enrichment of the mixture, and producing a smooth and positive acceleration of the engine.

The ACCELERATING PUMP provides the additional fuel needed for the accelerating system to furnish the temporarily rich mixture. The operation of the accelerating pump is shown in figure 7–5. The pump is shown as located in the float chamber, but in the actual carburetor it fits into a separate chamber that is in communication with the float chamber, and also with a passage to a spray nozzle that extends into the venturi tube.

By referring to figure 7–5, you will observe that the pump consists of an inverted sleeve, or cylinder, resembling a diving bell, which has a stem at the upper end operated by the throttle lever. Within the sleeve, a piston is free to slide on a hollow stem screwed into the main body casting. The upper end of this stem is shaped like a small poppet valve, and several holes in the wide face of the valve lead into the central hole of the stem. The piston forms the valve seat, and is held against the valve by a spring. The center hole of the stem connects with a passage leading to the main discharge nozzle (fig. 7–5),

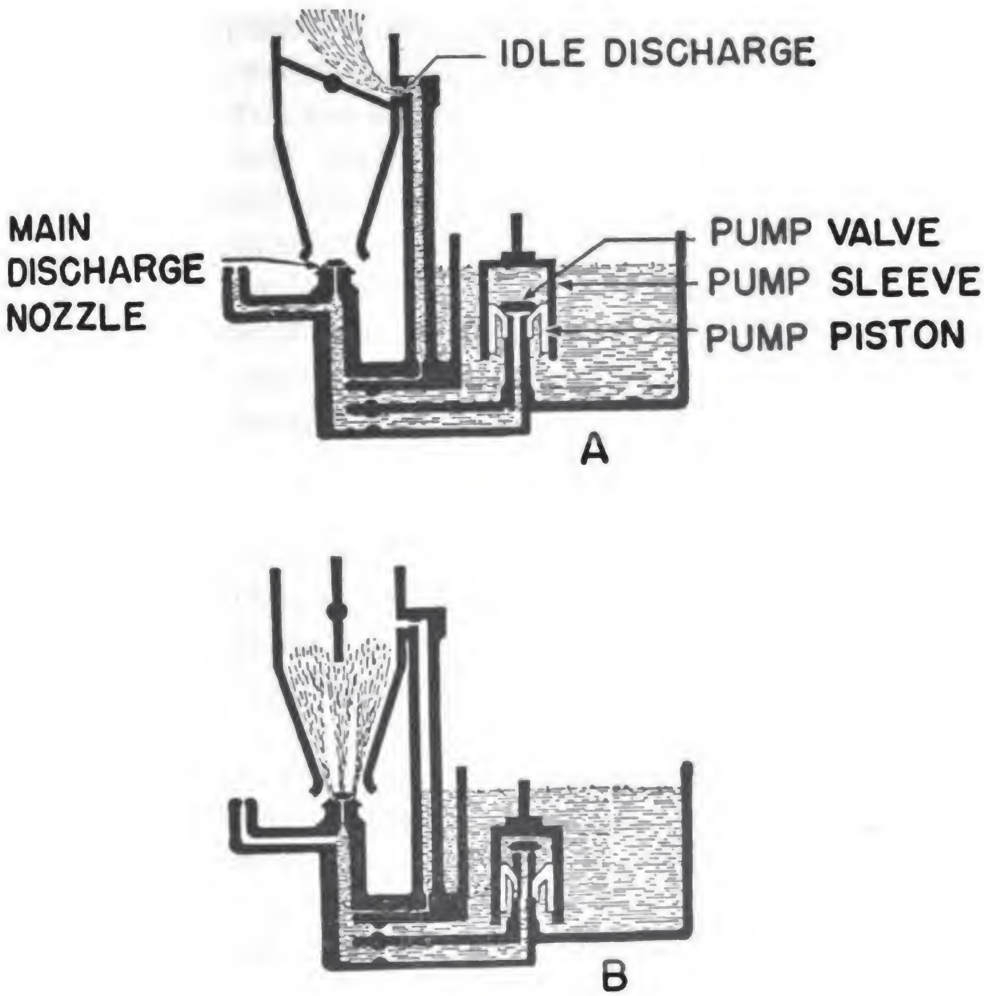


Figure 7–5.—Accelerating pump.

or to a separate discharge nozzle located just below the edge of the throttle valve.

When the throttle is closed, the cylinder is in its top position, as shown in view A of figure 7–5, and the space within it is filled with fuel. The pump is operated from the throttle valve through a mechanical linkage mechanism which is essentially an arm and a lever. When the throttle is opened rapidly, the cylinder moves down quickly. The pressure of the fuel, above the piston, forces the piston down and away from the poppet-valve top of the stem, thus uncovering the holes in the valve. The downward moving cylinder forces the fuel out of the discharge nozzle, as shown in view B

of figure 7–5. The spring then moves the piston up and forces the fuel, trapped between the piston and the valve head, out through the discharge nozzle. Therefore, the fuel discharge continues even after the throttle has reached the wide-open position. If the throttle remains open, the fuel flow through the accelerating system will stop as soon as the piston reaches the valve.

As the throttle is again partly or entirely closed, fuel is drawn into the pump cylinder through the clearance space between the piston and the cylinder. This arrangement provides automatic regulation of the fuel charge, depending upon the speed of the throttle opening. If the throttle is opened slowly, the fuel passes through the clearance space and back to the fuel chamber, without giving the engine an accelerating charge. (You may have used a tire pump in which the plunger was a loose fit. When you pushed the handle down slowly, you felt no resistance to its movement, but if you shoved it down quickly, you felt a definite air cushion under the plunger. This illustrates the action of the accelerator cylinder.)

Other types of accelerating pumps have the cylinder or sleeve fastened to a boss at the bottom of the float chamber by a special nut, which encloses a small spring-loaded check valve. A piston fits into the sleeve and is operated by the throttle. When the throttle is opened by the movement of the mechanical arm and lever, the fuel under the piston is forced out through the check valve to the discharge nozzle. During operation at any fixed throttle position, the check valve remains closed, and thus prevents any fuel discharge through the accelerating system.

Power Enrichment Devices

The proportion of fuel to air (fuel-air ratio) must increase as the engine approaches full power. To obtain this increase, various forms of enriching devices—usually referred to as economizers, or power compensators—are employed in modern carburetors. Applying the term economizer to an enrichening device may seem somewhat

confusing, because it implies the opposite effect. However, if no means were provided to give the mixture the richness required for high power, it would not be possible for the engine to run at the leaner (more economical) mixture suitable for cruising, or lower power, speeds. Without the economizer, it would be necessary to operate the engine at or above the best power mixture over the complete range to obtain the richness needed for high-power operation.

There are two general types of economizers, or power compensators, used with modern carburetors; the throttle-operated and automatically operated economizers. Both types are needle-valve mechanisms.

THROTTLE-OPERATED ECONOMIZER.—This type of economizer, shown in figure 7–6, consists of a pointed valve that controls an auxiliary fuel channel leading to the main discharge nozzle. The needle valve begins to open when the throttle valve has opened at a predetermined point. As the throttle continues to open, the needle valve does likewise, and the fuel flowing through the needle valve causes a richer mixture because it increases the fuel supply to the main discharge nozzle.

AUTOMATIC (POWER) ECONOMIZER.—In this type of economizer, the needle valve is held to its seat by a spring.

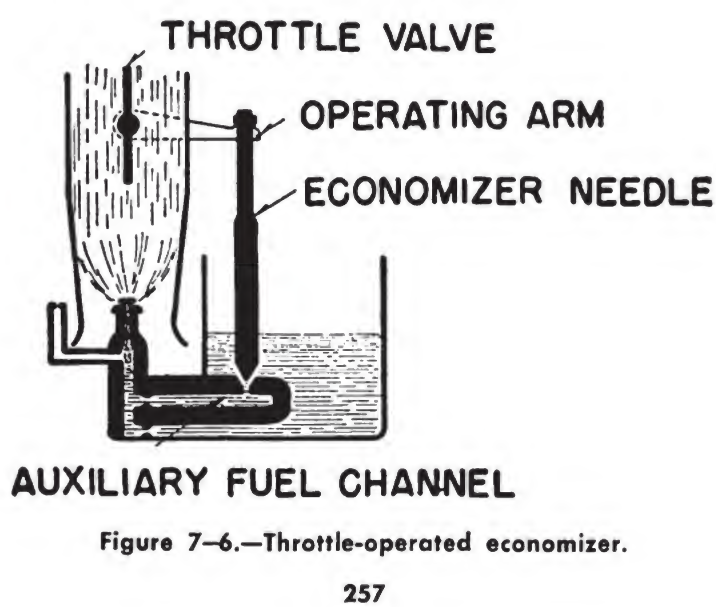


Figure 7–6.—Throttle-operated economizer.

An auxiliary venturi is provided in the fuel inlet of the carburetor. When there is a flow of fuel through this venturi, the pressure at the throat is less than the pressure at the entrance. The greater the fuel flow through the venturi, the greater the difference in pressure between the entrance of the venturi and the throat. This difference in pressure is used to operate the compensating valve.

When the fuel flow is increased to a point where the vacuum in the auxiliary venturi balances the pressure of the spring, the needle valve starts to open. Additional increase in the fuel flow through the venturi results in an increase in the valve opening. This valve supplies additional quantities of fuel directly from the fuel entrance to the discharge nozzle, and automatically provides the richer mixture required for higher power outputs.

ADJUSTMENT OF CARBURETORS

Failure of an engine to operate is rarely caused by carburetor defects. If it is determined that the carburetor is the source of trouble—that is, if the ignition system is functioning properly and the fuel is reaching the carburetor—the carburetor may be out of adjustment, the float level may be improper, or clogging of passages or jets may exist.

If it becomes necessary to make carburetor adjustments and repairs, carburetor tools, gages, and test equipment should be used. Special jet wrenches for removing or installing carburetor jets are preferable to the ordinary screw-driver bit, which is likely to chip or distort jet slots and openings. When float levels and metering rods require adjustment, the proper gages must be used in order to ensure correct settings. Exhaust gas analyzers and manifold vacuum gages are often helpful in adjusting carburetors. Analyzers indicate the completeness of combustion by registering the amount of carbon monoxide gas present in the exhaust gases. The dial may be calibrated in air-fuel ratio or in percentage of combus-

tion. The manifold vacuum gage indicates the amount of vacuum and whether the vacuum is constant.

When a carburetor is functioning with a medium or normal mixture, there is just enough air present in the combustion chamber to cause complete burning of all the fuel supplied. Desired carburetor settings will depend upon operating conditions. When maximum economy is desired, adjustments are made which provide an excess of air in the mixture. When conditions require maximum power, the carburetor is adjusted so that the mixture contains an excess of gasoline. Many multicylinder gasoline engines operate with a single carburetor. Because of this, some cylinders get a richer mixture than others. This happens because of differences in the lengths of manifolds and bends between the carburetor and the various cylinders. In such cases, the only thing to do is to adjust the carburetor so that the cylinder receiving the weakest mixture will still get a mixture strong enough for complete combustion.

If it becomes necessary to adjust the carburetor, all adjustments must be made in accordance with manufacturer's instructions. Figure 7–7 shows where some of the adjustments are made on one type of carburetor.

In general, the principal adjustments which may be made to modern carburetors are as follows:

1. ADJUSTMENT OF THE IDLE NEEDLE VALVE SCREW, sometimes referred to as the idle mixture or slow-speed adjusting screw. This adjustment controls the ratio of the fuel-air mixture for idling and slow operating speeds.

2. ADJUSTMENT OF THE THROTTLE VALVE STOP SCREW, or throttle idle adjusting screw, which usually controls the idling speed of the engine. (Figure 7–8 illustrates the adjusting screw of two different types of carburetors.)

When making an idle adjustment, first adjust the throttle stop on the carburetor so that the speed is sufficient to prevent the engine from stalling when the load is applied. Then open the idling needle or slow-speed adjusting screw until the mixture is so lean that it will

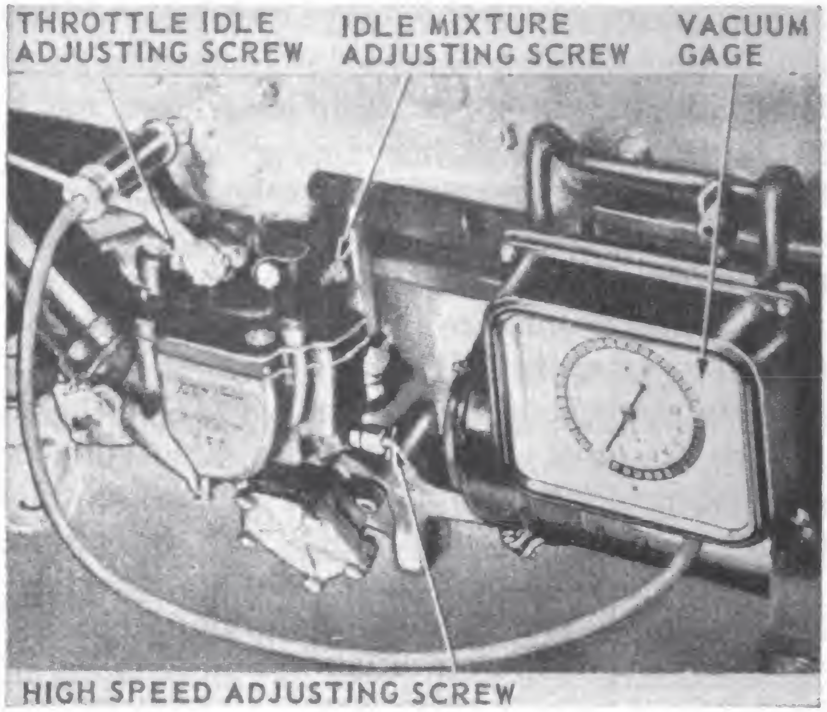


Figure 7–7.—Carburetor adjustments.

cause the engine to idle roughly. Then screw in the adjusting screw until engine operation smooths out. For smoothest idling, the mixture is richened slightly beyond this point. A final setting made to the throttle stop screw ensures an adequate idling speed.

On some installations, idling mixture adjustment is

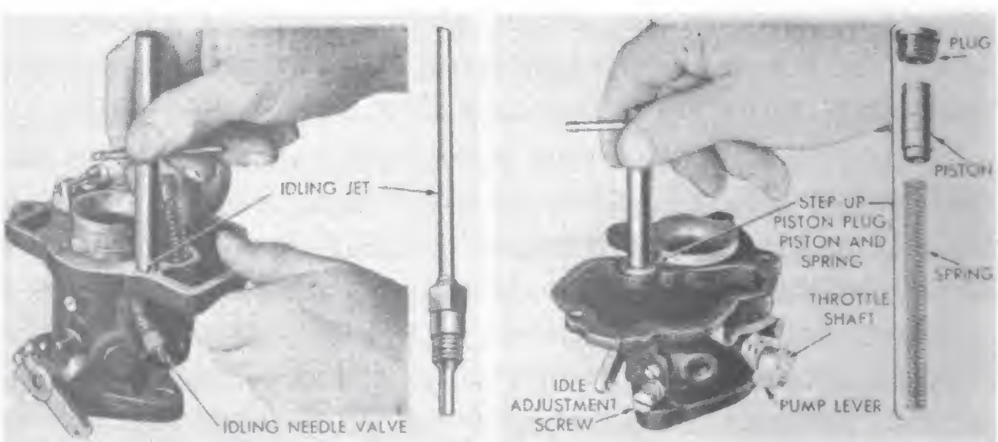


Figure 7–8.—Idling needle valve and idle adjustment screw of two different types of carburetors.

made by connecting a vacuum gage into the manifold above the carburetor. The idle mixture adjusting screw is then turned in the proper direction until the highest reading is reached where the gage indicator needle remains steady. The idle mixture should be correct when this point is reached.

3. ADJUSTMENT OF THE HIGH-SPEED MAIN JET.—This jet controls the ratio of the fuel-air mixture during cruising or high-speed operation. In some carburetors, this adjustment is made by a high-speed adjusting screw or needle valve; in other carburetors, the adjustment is made by changing to a larger or smaller main jet or to a richer or leaner metering rod. Figure 7–9 illustrates a main jet adjustment of one type carburetor (Zenith), and a main metering screw and needle assembly of another type carburetor (Carter).

A general method for making this type of setting on a carburetor with an adjustable screw or needle valve is as follows:

The engine is warmed up to service temperatures. If it is a boat engine, the boat should be taken into reasonably smooth water and run on a straight course at full throttle and advanced spark. In the case of engines used for auxiliary service, a steady full throttle and service operating temperatures are required.

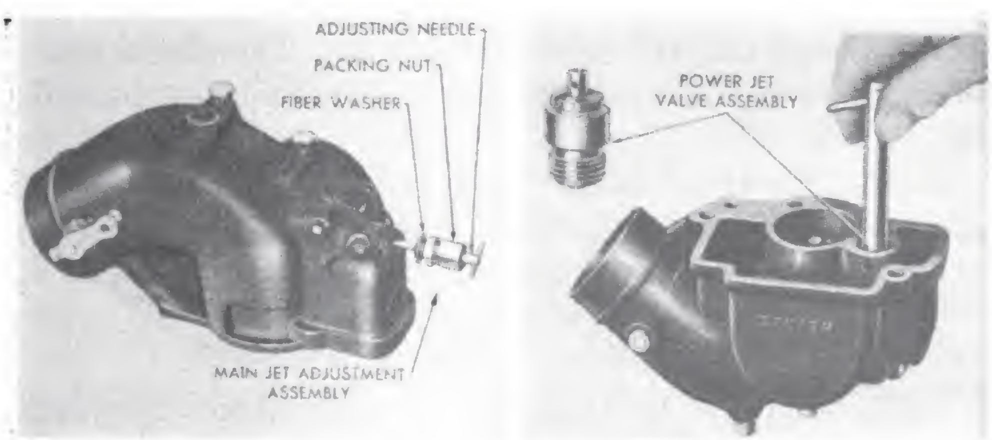


Figure 7–9.—Main jet adjustment and main metering screw and needle assemblies.

Adjustments are made to make a leaner mixture until the engine tachometer shows a decided drop and the engine just starts to miss. This is the point where some cylinders are beginning to get insufficient fuel. The sputtering and popping back, that occur, result from the mixture being so lean in certain cylinders that it does not burn as fast as it should. In this case, the mixture is still burning when the inlet valve opens; thus it ignites the inflowing charge and blows it back to the carburetor.

To get the best carburetor setting for economy, the mixture is enriched sufficiently above the "missing point" to bring about smooth running and a slight increase in engine speed. If maximum power is desired, the same procedure is employed except, instead of enriching only slightly, the mixture is made richer and richer until a point is reached where further enriching of the mixture does not produce an increase in rpm. The setting for best general performance is usually between the two extremes, slightly to the rich side.

4. ADJUSTMENT OF SOME PART OF THE CHOKE OR PRIMING MECHANISM.—This adjustment provides for a greater or lesser amount of choke effect when starting the engine.

As with all maintenance procedures, adjusting the choke varies from one engine to another. In general, the linkage is disconnected, then the choke button is pushed all the way in, and then pulled out slightly—in some cases, about 1/16 inch. The choke valve is then held against the stop and the linkage is connected. The choke should be adjusted so that it closes fully when the button is pulled all the way out.

5. ADJUSTMENT MADE TO CORRECT THE DISTANCE OF ACCELERATING PUMP TRAVEL.—This adjustment is done in order to produce the proper amount of fuel required for acceleration and to time its movement to meet the sudden demand incident to such acceleration.

Adjustments of this type may be made either by moving the linkage rod between the throttle and the acceleration pump into one of the various holes provided in the throttle

or pump lever, or by bending the linkage to secure a shorter or longer stroke.

6. ADJUSTMENT OF THE FLOAT LEVEL is accomplished to regulate and control the movement of the fuel from the fuel pump into the carburetor float chamber. The float level must be in accordance with manufacturer's specifications, if the needle valve is to actuate properly in regulating the flow of fuel. Because of wear, the float level may rise, permitting flooding and an excessively rich mixture. If the level is too low, the mixture will be too lean. The procedures for measuring and adjusting the float level will vary, depending upon the carburetor involved.

Figure 7–10 illustrates the measuring of float level on two different types of carburetors (Zenith and Carter). For the carburetors illustrated, the float bowl cover had to be removed and the fuel height or float-level position measured. This measurement is usually taken between the fuel or float and the top of the bowl, or between the bowl cover and a marking on the float. Adjustment is made by bending the lip that actuates the needle valve.

It is possible to install a float-level gage on some carburetors, while on others an inspection plug may be removed for checking float-level height without disassembling the carburetor.

7. ADJUSTMENT OF THE CONTROL RODS.—Lengthening or shortening these rods regulates the action of float valves, metering rods, accelerating pumps, and similar parts.

MAINTENANCE OF CARBURETORS

The possibility of carburetor clogging can be reduced if fuel filters are drained and cleaned periodically. Even so, it is possible that foreign material, such as water or dirt, may get through the system to clog the jets of a carburetor. When this happens, it will be necessary to remove and clean the carburetor. In some cases, the

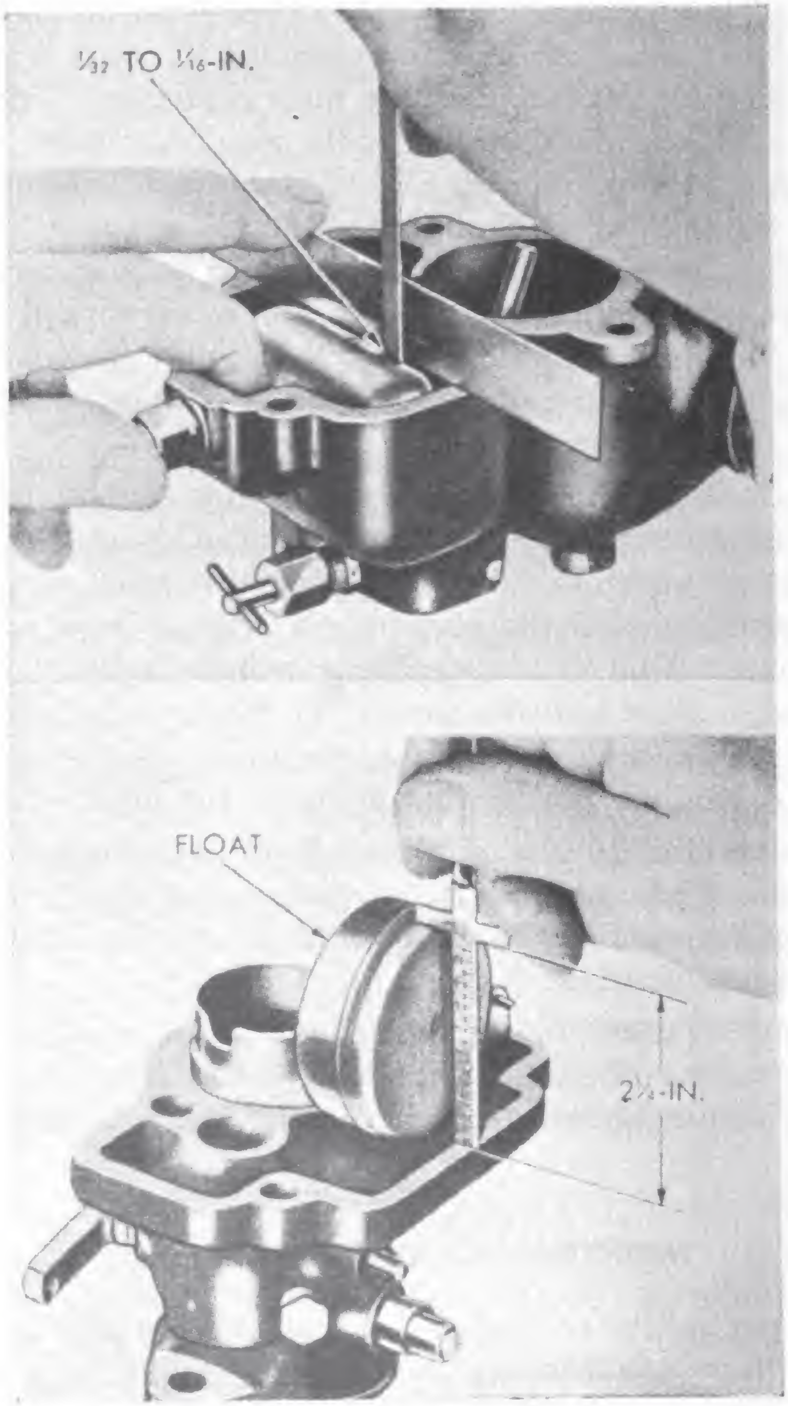


Figure 7–10.—Measuring carburetor float level.

carburetor may be replaced and the defective unit sent to a carburetor shop for maintenance. In case a replacement is used, make certain that the unit is identical in size, shape, and model number with the one removed. The mounting flange must match, and linkage and piping connections must all be identical.

Before a carburetor is removed, see that all controls and piping connections are disconnected. All line connections should be protected to prevent damage. After removal, a carburetor must be handled carefully. It should be held in an upright position; if it is allowed to tilt, any accumulation of sediment in the fuel bowl may enter and clog the jet openings.

The disassembly, cleaning, inspection, repair, and assembly of a carburetor must be made in accordance with the specific manufacturer's instructions. However, the discussion which follows applies, in general, to most carburetors.

Before a carburetor is disassembled, its exterior should be washed with an approved solvent and dried with compressed air. After disassembly, the initial cleaning involves soaking the various castings (such as the upper and lower body halves, shown in figure 7–11) and the small parts in an approved solvent, after which the units are dried with compressed air. All passages must be cleaned and carbon deposits removed. The use of com-

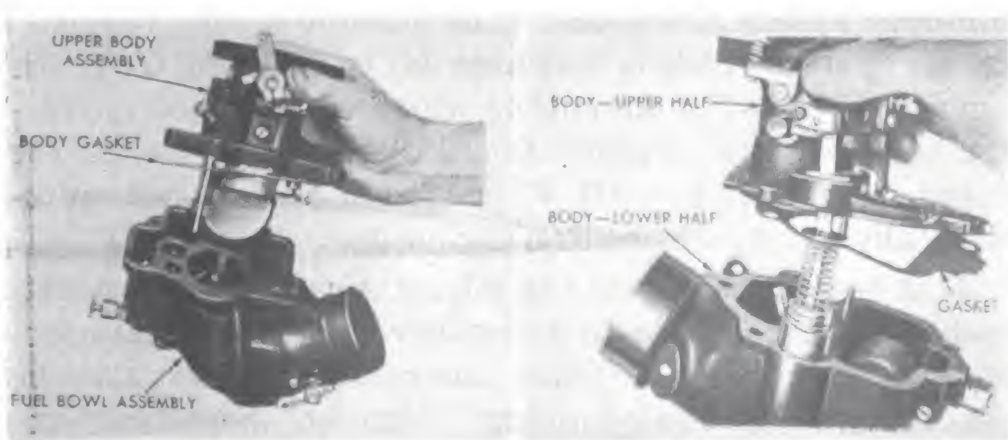


Figure 7–11.—Carburetor Body Assemblies.

pressed air facilitates cleaning of passages, and sandpaper is most helpful in removing carbon from the carburetor throat where the throttle valve seats. Clogged jets should not be cleaned with a wire or metal pin; always use compressed air or a soft wooden cleaning rod.

Whenever a carburetor is removed, examine the throttle valve to see that it is operating properly. Check the float valves for leaks; replace a leaky float rather than attempt to repair it.

When a carburetor is being installed, see that all gaskets are properly seated and in satisfactory condition. Start all the flange nuts before tightening any particular one, then draw them all down evenly. Tightening one flange nut or bolt before tightening the others may result in a broken or cracked flange. After installation, see that all controls are connected and that the piping joints are secure. Install the air cleaner and make all necessary adjustments as specified in the manufacturer's instruction manual.

SUMMARY

Under all operating conditions, the carburetor must accurately meter the incoming fuel and air so that the mixture entering the cylinders is of the proper proportion. The amount of fuel mixed with the air must be carefully regulated, and must change with the engine's different speeds and loads. The amount of fuel required by an engine which is warming up is different from the amount required by an engine which has reached operating temperature. Special fuel adjustment is needed for rapid acceleration. All these requirements are automatically met by the modern carburetor.

If it becomes necessary to adjust a carburetor, adjustments must be made in accordance with the manufacturer's instructions. These instructions must also be observed when disassembling, cleaning, inspecting, repairing, and assembling carburetors.

QUIZ

1. In an operating gasoline engine, what regulates the speed with which the air flows through the venturi of the carburetor?
2. If the carburetor does not have an accelerating system and the throttle is opened suddenly, what type of mixture is produced?
3. What is the function of the accelerating pump?
4. As the engine approaches full power, what type of devices are used on modern carburetors to obtain an increase of the fuel-air ratio?
5. What are three principal troubles which may prevent a carburetor from functioning properly?
6. If the design is such that some cylinders of a gasoline engine get a richer mixture than others, how should the carburetor be adjusted?
7. When making an idle adjustment, what is the first step to be taken?
8. When adjusting a carburetor for the best general performance, is the final setting to the rich side or the lean side of the adjusting range?
9. What factors are involved when a gasoline engine fails to operate properly because the accelerating pump of a carburetor does not travel the correct distance?
10. What adjustment is generally made when it is necessary to regulate and control the flow of fuel from the fuel pump to the carburetor?
11. After a carburetor has been removed from its engine mounting, why should it be held in an upright position?
12. What should be used to clean the clogged jets of a carburetor?

CHAPTER 8

ENGINE MAINTENANCE

In order to keep an internal combustion engine (Diesel or gasoline) in satisfactory operating condition, it is necessary to follow a well-planned procedure of periodic inspections, adjustments, maintenance, and repair. If inspections are made regularly, early failure, maladjustment, or excessive clearance of wearing parts can be detected and corrected before any serious casualty results.

Since the Navy uses so many models of internal combustion engines, it is impossible to specify any detailed maintenance or overhaul procedure adaptable to all engines. However, the following rules apply, in general:

1. Detailed maintenance and repair procedures are listed in manufacturers' instruction manuals and progressive maintenance pamphlets. Study the appropriate manuals and pamphlets before attempting to perform any maintenance. Pay particular attention to wear limits, tolerances, and adjustments.
2. The highest degree of cleanliness must be observed in handling engine parts during overhaul.
3. Before starting to maintain or repair engine parts, see that all required tools and repair parts are available; this will ensure successful and rapid completion of the work.

Since the progressive maintenance pamphlets and the manufacturers' books discuss maintenance and repair procedures in detail, this chapter will be limited to general

information on the care and maintenance of engine parts, such as cylinder liners, positions, valves, and bearings.

CYLINDER ASSEMBLIES

All cylinder assemblies perform the function of retaining the gases of combustion as long as necessary for accomplishing the power stroke. Although the design of cylinder assemblies may vary considerably, they all have

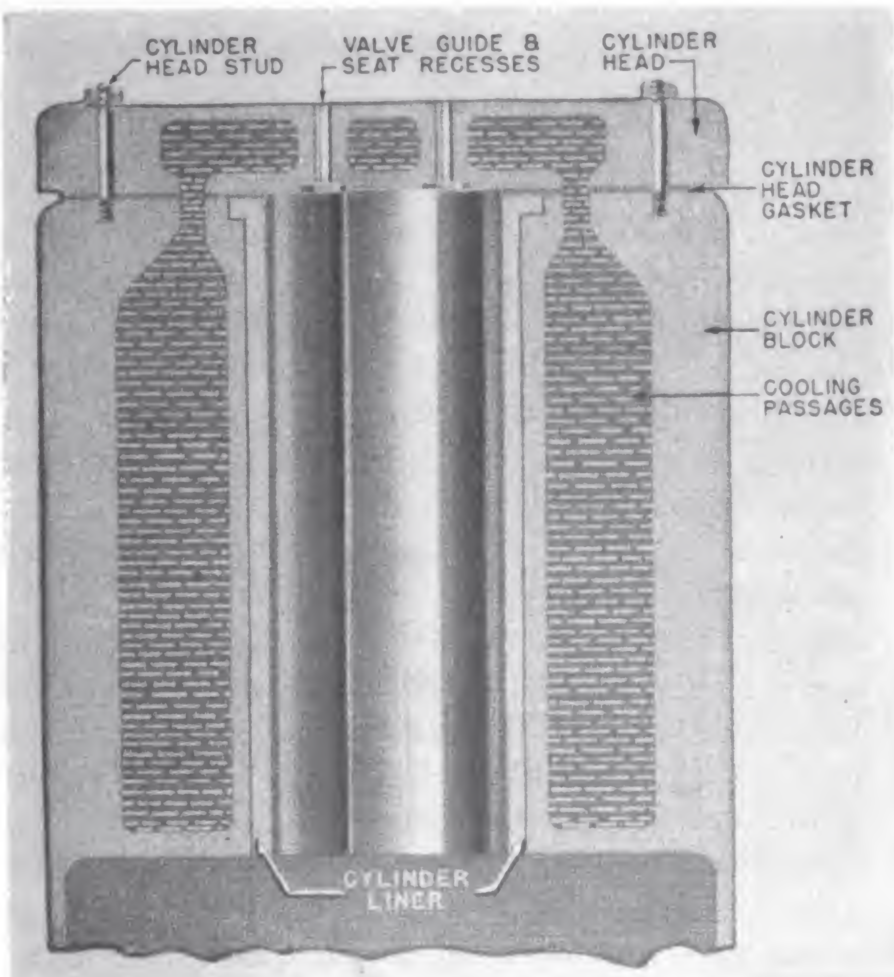


Figure 8–1.—Schematic diagram of a cylinder assembly.

the same basic components—liner (or bore), head, gaskets, and studs. Figure 8–1 illustrates a schematic diagram of a cylinder assembly.

Liners

Maintenance and repair procedures for liners vary, depending upon the engine. Troubles which may require maintenance or repair of cylinder liners are cracks, scoring, obstructed ports, or excessive wear. If an inspection of the cylinder liner indicates that it must be removed for repair or replacement, follow the instructions given in the manufacturer's manual for the particular type of engine. Figure 8–2 illustrates the method generally used to remove a cylinder liner.

If it becomes necessary to remove the cylinder liner of an engine, proceed as follows:

1. Remove the pipe plug which is threaded into the liner plug, and drain the cooling water. After the liner is drained, remove the liner plug.
2. Remove the cap screws which hold the inlet water header flange to the liner. Loosen the flanges on the two adjacent liners to assist in removing the liner on which work is being done.
3. Attach the special liner puller to the liner studs, and tighten the cap nuts by hand. (The cap nuts must be hand tightened; if a wrench is used, the threads on both nuts and studs will be damaged.)
4. Attach the hook of the chain fall, and pull slightly until the liner breaks free (fig. 8–2). If the liner fails to break loose immediately, it will be necessary to apply pressure at the bottom. To do this, place a block of wood on the crankshaft throw, and force it up against the liner by rotating the turning gear.
5. Lift the liner up until it clears the top of the engine block, and remove it to a safe place. It may be necessary to rotate the liner slightly while removing it from the engine block.

CRACKS in liners may logically be suspected when any of the following occur: excessive water in the lubricating oil, an accumulation of water in a cylinder of a secured engine, an abnormal decline in the water level of the ex-

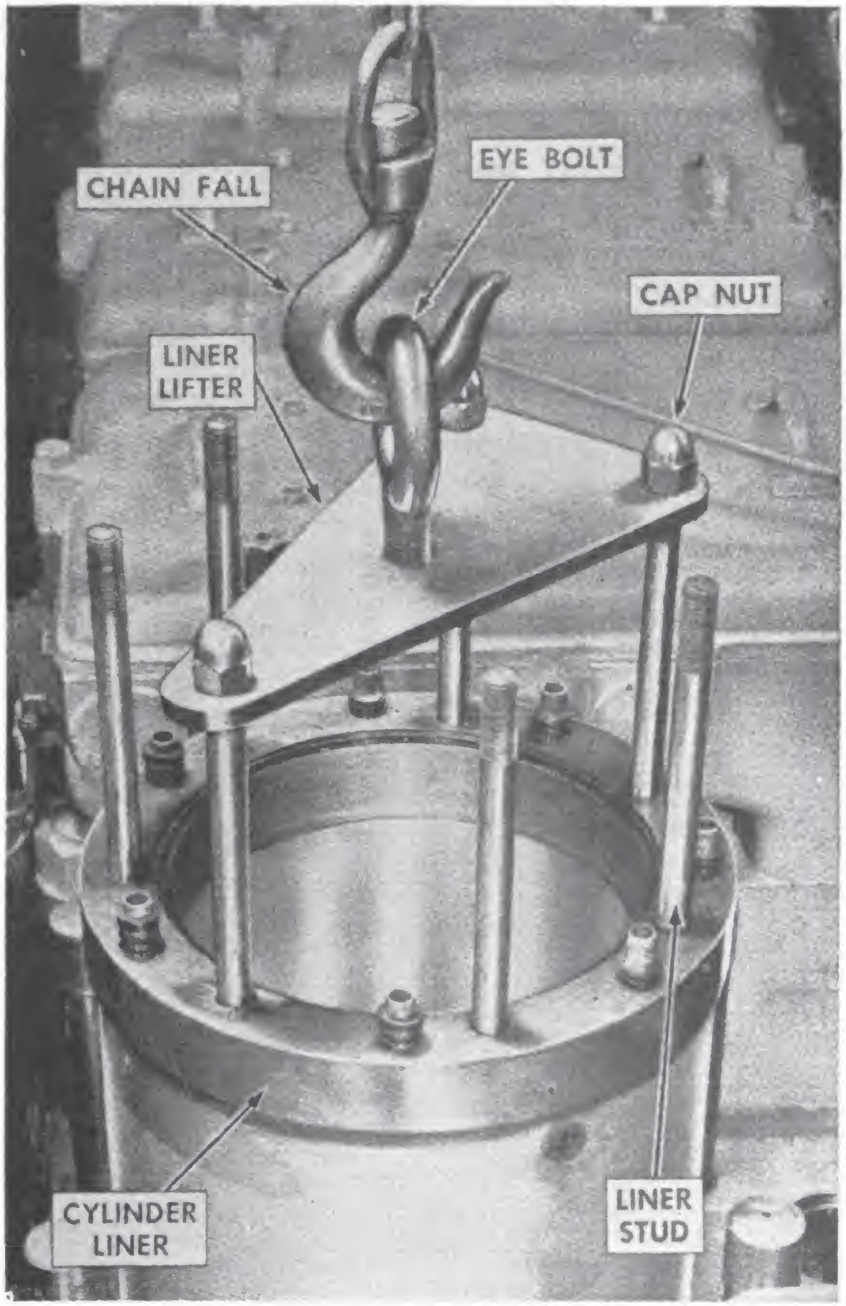


Figure 8–2.—Removing a cylinder liner.

pansion tank, excessive temperature of the cooling water resulting from the combustion gases blowing into the cooling passages, or gas in the cooling water.

If cracks cannot be located by visual inspection, other methods must be used. After removal from the engine, liners with integral cooling passages may be checked by

plugging the outlets and filling the passage with glycol-type antifreeze. This liquid will leak from even the smallest cracks. (Figure 8–3 illustrates a wet-type liner with integral cooling passages.) Cracks in dry liners, however, may be more difficult to locate, for no leakage of water will occur as a result of such cracks. The location of cracks in dry liners may require the use of magnaflux equipment; this is discussed later in the chapter.

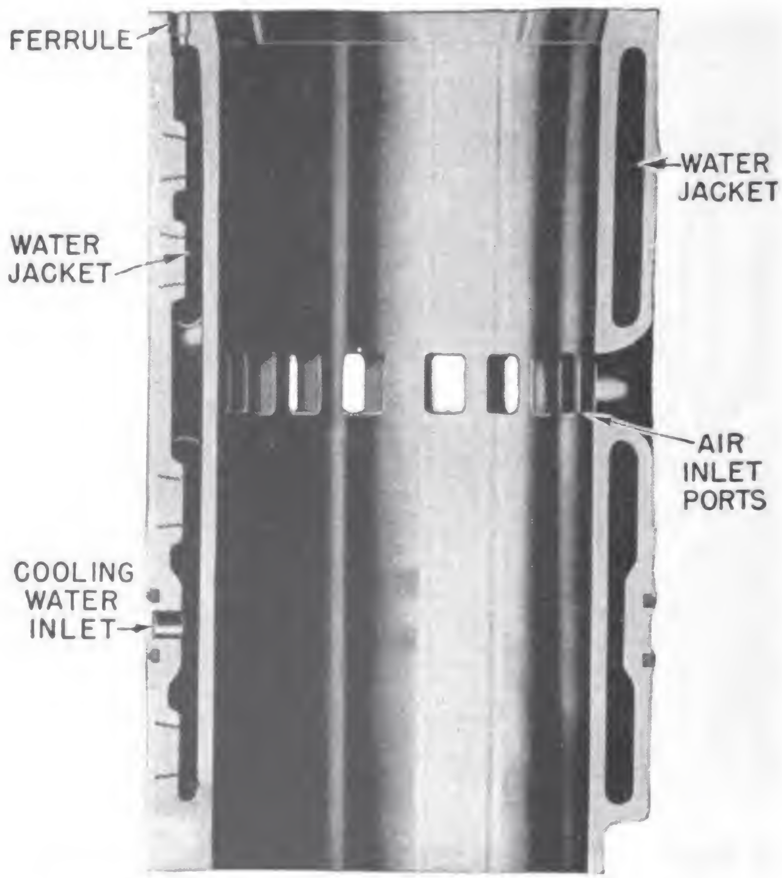


Figure 8–3.—Wet liner with integral cooling passages.

Cracking of cylinder liners (fig. 8–4) may result from poor cooling, improper fit of piston or pistons, incorrect installation, foreign bodies in the combustion space, or erosion and corrosion.

IMPROPER COOLING, which generally results from restricted cooling passages, may cause uneven heating of

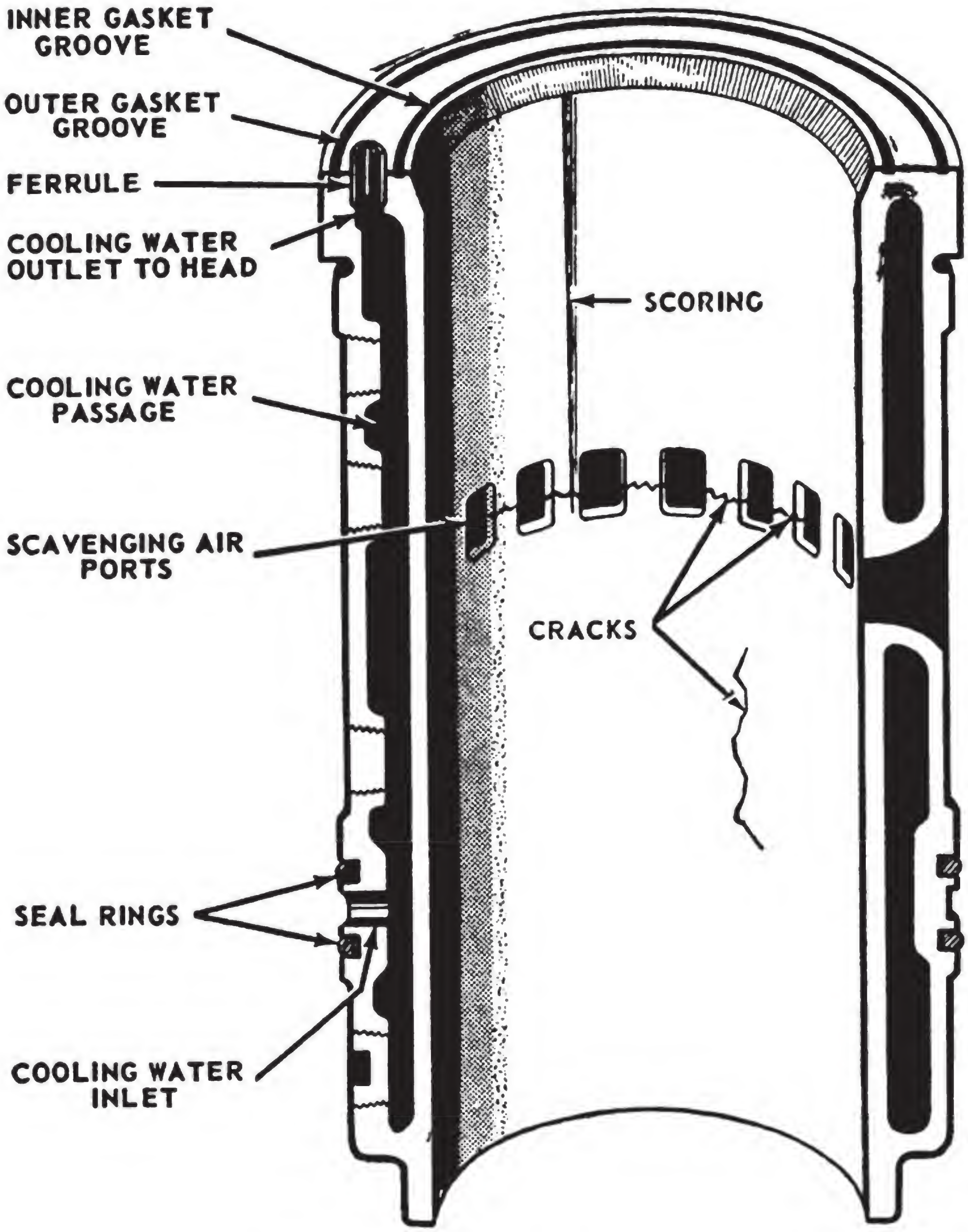


Figure 8–4.—Cylinder liner casualties.

liners, and liner failure then occurs as a result of thermal stress. Uneven heating of liners may also result from the formation of scale on the cooling passage surfaces; wet liners are subject to scale formation. Scale may be removed by following the procedures outlined in Chapter 41 (section II, part 10) of BuShips *Manual*.

Proper cooling of dry liners requires clean surfaces of contact between the liner and cylinder block. Particles

of dirt between these surfaces cause air spaces which are poor conductors of heat. Films of oil or grease on these mating surfaces also offer resistance to the flow of heat.

IF PISTONS DO NOT FIT PROPERLY, excessive clearance between the liner and piston will result in piston slap. The forces created may cause breakage, distortion, or excessive wear. However, pistons which fit improperly will seldom be a problem if instruction manuals and progressive maintenance schedules have been followed. Pistons and liners should be replaced when their wear reaches the maximum allowable liner wear as specified in the manufacturer's instruction manual.

DISTORTION, WEAR, OF BREAKAGE may result if a liner is not properly seated. Cause of improper liner seating may be metal chips, nicks, or burrs, or improper fillets. Figure 8–5 illustrates a case where an improper fillet on

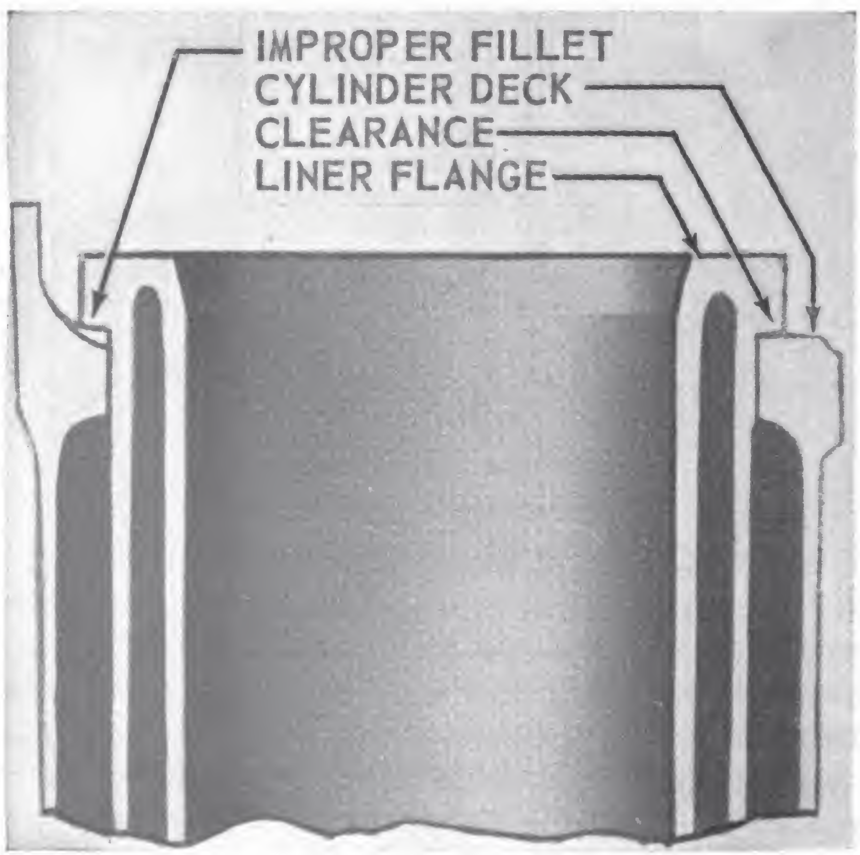


Figure 8–5.—Improperly seated cylinder liner.

the cylinder deck prevents proper seating. The fillet should be ground down until there is no clearance between the lower surface of the flange and the mating surface of the cylinder deck.

The use of an oversized sealing ring may cause improper positioning of the liner. As the sealing ring is overcompressed, the rubber loses its elasticity and becomes hard. This may result in distortion of the cylinder.

The clearance between the mating surface can be checked with feeler gages. If the instruction manual specifies the distance from the cylinder deck to the upper surface of the liner flange, this dimension can be used to check on the seating of the liner.

OBSTRUCTIONS in the combustion chamber may be destructive not only to the liner but also to the cylinder head and other parts. EROSION AND CORROSION may take place in a few isolated spots and weaken a liner sufficiently to cause cracks.

Replacement is the only satisfactory means of correcting for cracked, broken, or badly distorted cylinder liners.

SCORED CYLINDER LINERS.—Scoring may be in the form of deep or shallow scratches in the liner surface (fig. 8–4). In most cases of scoring, corresponding scratches will be found on the piston and piston rings. The symptoms of scoring may be low firing or compression pressure and rapid wear of piston rings. Visual inspection is the best method for detecting scoring and may be accomplished through liner ports, through the crankcase housing with pistons in top position, or when the engine is disassembled.

Scored cylinder liners may be caused by broken piston rings, defective pistons, improper cooling, improper lubrication, or the presence of foreign particles. Dust particles drawn into an engine cylinder will mix with the oil and become an effective but undesirable lapping compound that may cause extensive damage. The importance of keeping the intake air clean cannot be overemphasized. Another precaution that should be taken is to see that, when assembling an engine, no metal chips, nuts, bolts,

screws, or tools remain in cylinder when the head is replaced.

Pistons and rings which are badly worn permit blow-by of combustion gases. Not only is operating efficiency reduced, but there is also a greater tendency for scoring, both because of the increased temperature, and because blow-by may reduce the oil film until metal-to-metal contact takes place. Inspect the pistons and rings carefully. A piston with a rough surface (such as one that has seized) will cause scoring of the liner.

Scoring as a result of insufficient lubrication or dirt in the lubricating oil can be prevented if lubricating equipment (filters, strainers, and centrifuges) is maintained properly. Lube oil must be purified in accordance with required procedures.

Repair of scored liners is not generally undertaken by ship's force. Spare liners are installed. When necessary, liners with minor scoring may be kept in service, if the cause of scoring is eliminated, and the minor defects can be corrected. The surface of the liner must be inspected carefully, especially in the region adjacent to the

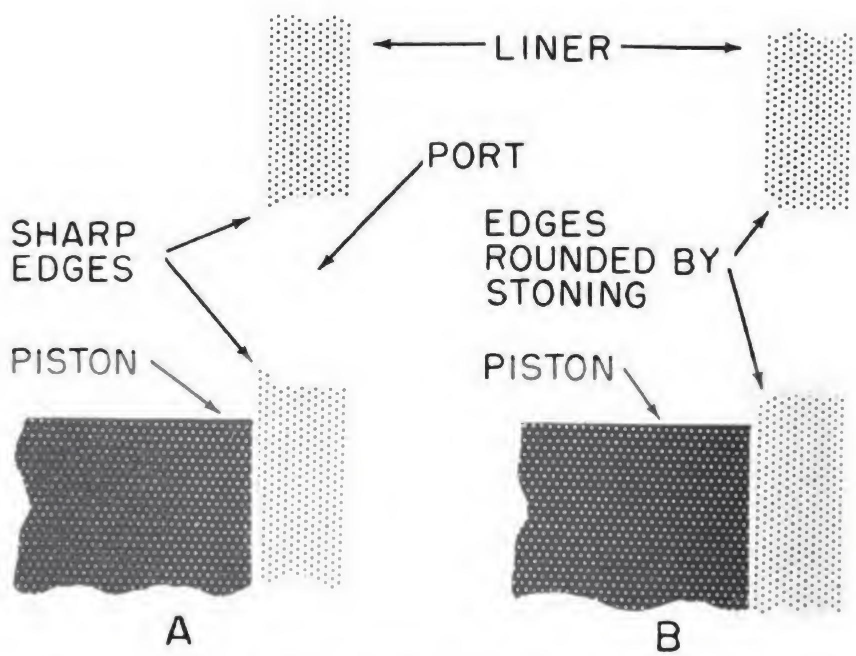


Figure 8–6.—Liner ports before and after stoning.

ports, for any burrs, projections, or sharp edges that would interfere with piston and ring travel. Most projections can be removed by hand-stoning, using a fine stone. A liner before and after stoning the ports is shown in figure 8–6.

EXCESSIVE WEAR. The best method of determining whether excessive wear has taken place is to take measurements of the cylinder liner with inside micrometer calipers. The types of liner wear to be checked are illustrated in figure 8–7.

Clearance between a piston and a liner is generally checked by micrometer measurements of both parts. On smaller engines, however, a feeler gage can be used. Clearance in excess of that specified by the manufacturer is generally due to liner wear, which normally is greater than piston wear.

Measurements for determining liner wear should be taken at three levels. Make the first measurement slightly below the highest point to which the top ring travels, take the next measurement slightly above the lowest point

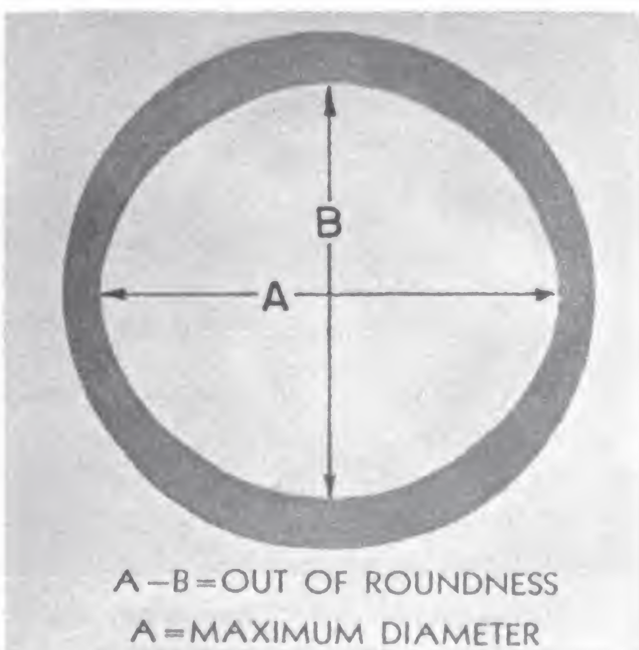
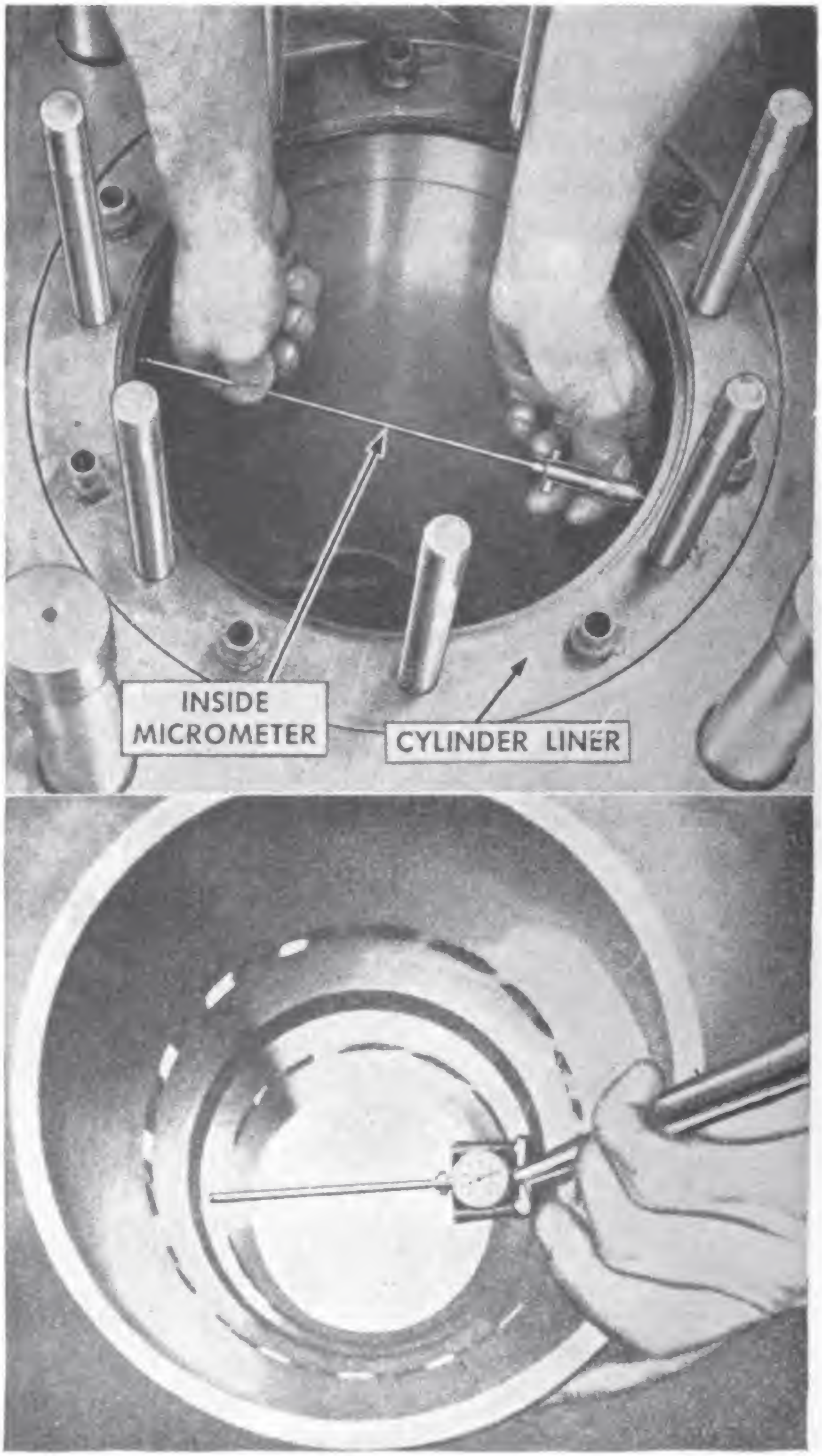


Figure 8–7.—Measurements for determining liner wear.



Top (A) Bottom (B)

Figure 8–8.—Measuring the inside of a cylinder liner.

of compression ring travel, and the third measurement at a point about mid-way between the first two. (All readings should be recorded, so that rapid wear of any particular cylinder liner will be evident to the operator.) If excessive wear or out-of-roundness exists beyond specified limits, the liner should be replaced. Figure 8–8 shows two examples of taking inside measurements. The liner shown in B of figure 8–8 is for an opposed piston engine and requires at least twice as many measurements as other types of liners.

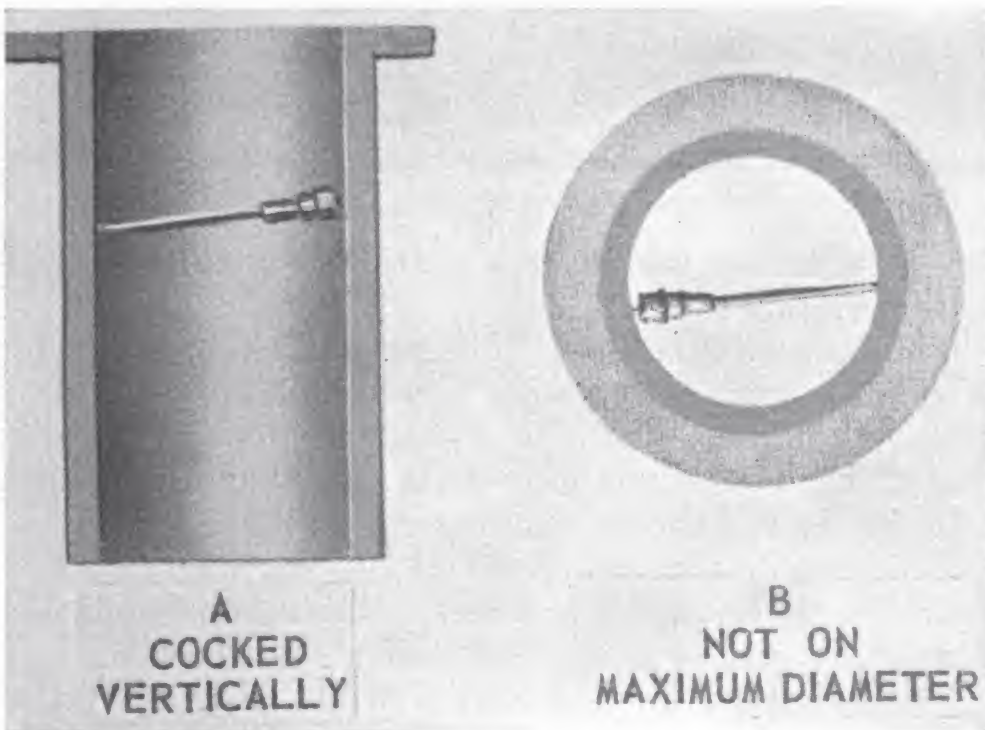


Figure 8–9.—Errors to avoid when making liner measurements.

Accurate measurements cannot be obtained unless the caliper or gage is properly positioned in the liner. Common errors in positioning are illustrated in A and B of figure 8–9. One end of the caliper should be held firmly against the liner wall, as shown in A of figure 8–9. The free end can then be moved back and forth, and up and down, until the true diameter of the liner is established.

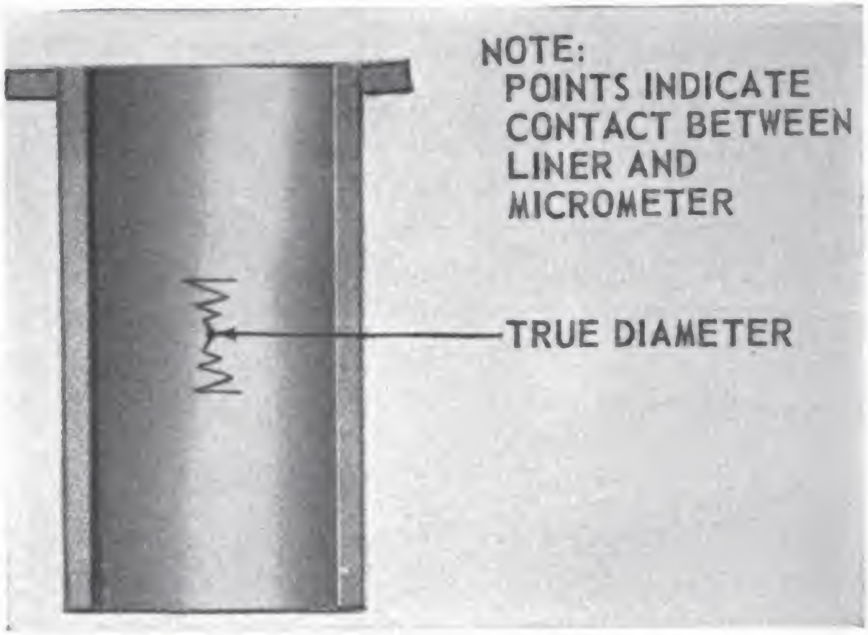


Figure 8–10.—Trace of caliper end when determining true diameter of a liner.

The moving end will trace a path similar to that illustrated in figure 8–10.

Considerable experience in using an inside micrometer or cylinder gage is necessary to ensure accuracy. As a precaution against error, it is good practice for two persons to take the liner measurement; then any discrepancy between the two sets of readings can be rechecked.

Excessive or abnormal wear of cylinder liners may be caused by too low a cooling water temperature, insufficient lubrication, dirt, or improper starting procedures.

The cooling water of an engine should always be maintained within the specified temperature ranges. If the temperature is allowed to drop too low, corrosive vapors will condense on the liner walls.

Care must be exercised to maintain the lubricating system in proper working order. The method of cylinder liner lubrication varies with different engines. The proper grade oil, in accordance with engine specifications, should be used.

The engine must not be operated in a dirty condition. The air box, crankcase, and manifold should be cleaned,

and maintained in such condition, to avoid cylinder wear and scoring. (Attention to the air cleaner, oil filters, and oil centrifuge are the best precautions against the entrance of dirt into the engine.)

Improper starting procedures will cause excessive wear on the liners and pistons. When an engine is first started, some time may elapse before the flow of lubricating oil is complete; also, the parts are cold and condensation of corrosive vapors is accordingly accelerated. These two factors (lack of lubrication and condensation of corrosive vapors) make this period immediately after starting a critical one for cylinder liners. If an independently driven oil pump is installed, it must be used to prime the lube oil system and build up oil pressure before the engine is started. The engine should not be subjected to high load during the warm-up period—in fact, it is best to warm it up to the operating temperature before applying any load.

Cylinder liners worn beyond the maximum allowable limit should be replaced. Maximum allowable wear limits may be found in engine instruction manuals, the progressive maintenance pamphlet, or the Diesel Engine Wear Limit Chart available from BuShips. In the absence of such specific information, the following wear limits (established by BuShips) apply in general to:

1. Two-stroke cycle engines with aluminum pistons: 0.0025 inch per inch diameter.
2. Slow-speed engines over 18 inch bore: 0.005 inch per inch diameter.
3. All other engines: 0.003 inch per inch diameter.

Heads

Conditions requiring maintenance and repair of a cylinder head are, in many ways, similar to those encountered in cylinder liners, and can be grouped, in general, under CRACKS, CORROSION, DISTORTION, and FOULING.

CRACKS.—The symptoms of a cracked cylinder head are the same as those of a cracked liner. Cracks in cyl-

inder heads are best located by a visual or a magnetic powder inspection. On some types of engines, the defective cylinder may be located by bringing the piston of each cylinder, in turn, to top dead center, and applying compressed air. When air is applied to the damaged cylinder, a bubbling sound will indicate leakage.

When removed from the engine, the cylinder head may be checked for cracks by the hydrostatic test that is used on cylinder liners equipped with integral cooling passages.

Cracks generally occur in cylinder heads on the narrow metal sections existing between such parts as valves and injectors. The cracks may be caused by the addition of cold water to a hot engine, by restricted cooling passages, by obstructions in the combustion space, or by improper tightening of studs.

On board ship, cracked cylinder heads generally have to be replaced. It is possible to repair them by welding, but this process requires the special equipment and highly skilled personnel, generally found only at repair activities.

CORROSION.—Burning and corrosion of the mating surfaces of a cylinder head may be caused by a defective gasket. Although regular inspection and maintenance generally prevent the occurrence of this type of trouble, burning and corrosion may take place under certain conditions. When corrosion and burning occur, there may be a loss of power as a result of combustion gas leakage, or leakage of water into the combustion space. Another symptom of the trouble might be hissing or sizzling in the area of the head where gases, or water, may be leaking between the cylinder head and the block.

Gaskets and grommets which seal combustion spaces and water passages must be in good condition; otherwise leakage of the fluids will cause corrosion or burning of the areas contacted. Improper cooling water treatment is another factor which may accelerate the rate of corrosion.

In general, cylinder heads which become burned or cor-

roded as a result of gas or water leakage are damaged to such an extent that replacement is necessary.

DISTORTION.—Warpage or distortion of cylinder heads is apparent when the mating surfaces of the head and block fail to conform. In some severe cases, the head will not fit over the studs. Distortion may be caused by improper welding technique in the repairing of cracks, or by improper tightening of cylinder head studs. In isolated cases, new heads may be wrapped because of improper casting or machining processes.

Repair of distorted cylinder heads is impracticable. They should be replaced as soon as possible.

FOULING.—If the combustion spaces become fouled, the efficiency of combustion will decrease. Combustion chambers are designed to create the desired turbulence for mixing the fuel and air; any accumulation of carbon deposits in the space will impair both turbulence and combustion by altering the shape and decreasing the volume of the combustion chamber.

Symptoms of fouling in the combustion spaces are smoky exhaust, loss of power, or high compression. Such symptoms may indicate the existence of extensive carbon formation, or clogged passages. In some engines, these symptoms indicate that the shutoff valves for the auxiliary combustion chambers are stuck.

Combustion chambers may also become fouled because of faulty injection equipment, improper assembly procedures, or excessive oil pumping.

Cleaning of fouled combustion spaces generally involves removing the carbon accumulation. The best method is to soak the dirty parts in an approved solvent, and then to wipe off all traces of carbon. A scraper may be used to remove carbon, but care must be exercised to avoid damaging the surfaces. If oil pumping is the cause of carbon formation, check the wear of the rings, bearings, pistons, and liners. Replace or recondition excessively worn parts. Carbon formation resulting from improperly as-

sembled parts can be avoided by following the procedure described in the manufacturer's instruction manual.

Studs

All stud nuts should be tightened equally, and in accordance with specifications given in the instruction manual. Overtightening is as undesirable as undertightening. In many cases, studs that are relatively inaccessible are neglected during the periodic checks for tightness. Such an oversight may result in studs coming loose and failing.

When installing stud nuts, the threads of the studs and the nuts should be carefully cleaned by wire-brushing and applying an approved solvent. This will minimize wear and distortion of threads resulting from dirt, as well as increase the accuracy of the torque wrench readings. (It is evident that a higher torque wrench reading will be necessary to reach required tension when the treads are dirty than when they are cleaned and well lubricated.)

Figure 8–11 illustrates an order for tightening studs for two types of cylinder heads. This order is not a hard

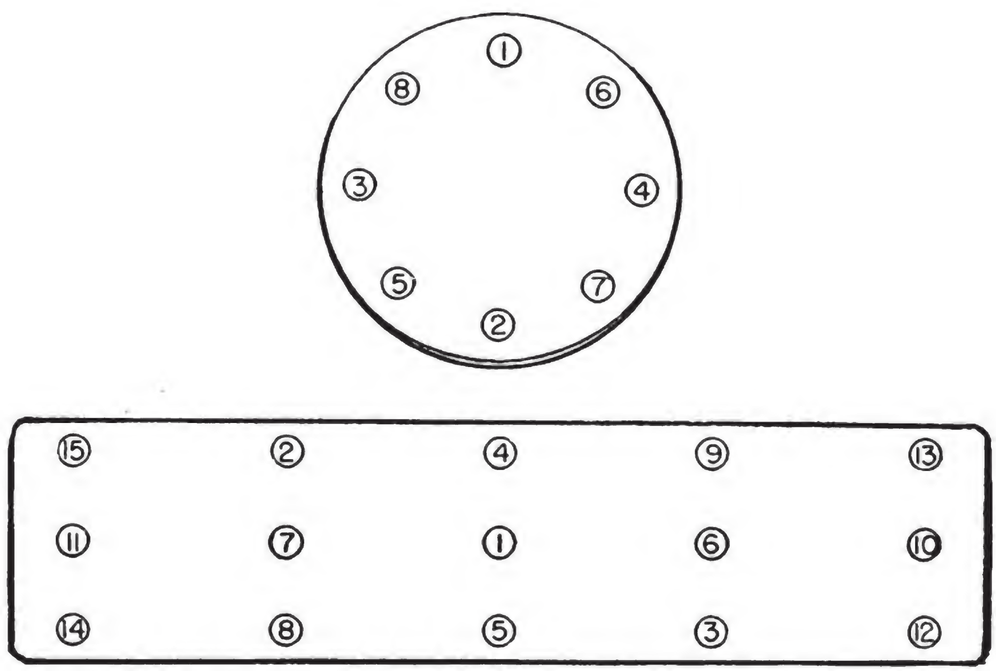


Figure 8–11.—Order of sequence for tightening cylinder head studs.

and fast rule but can be followed in the absence of more specific information. Studs are generally tightened sufficiently to seat the cylinder head lightly, finger tight. At least two or three rounds of tightening should be made before bringing all studs up to the specified torque.

Gaskets

Leakage is the chief trouble encountered with gaskets. Leakage becomes apparent when the compression pressure becomes low, resulting in starting difficulties, or when fluid escapes between the head and block. In some cases, there may be no external leakage from a defective gasket. The only way to positively determine internal leakage is by removing the cylinder head.

Leaky gaskets may be the result of a permanently compressed gasket, improper tightening of cylinder head stud nuts, careless installation of the gasket, or the installation of a damaged or defective gasket.

After prolonged use, gaskets become permanently compressed and lose their ability to conform to irregularities in the machined surfaces. In such cases, leakage will occur past the gasket, and the operator will attempt to stop the leakage by tightening the hold-down, or cylinder head, nuts. A gasket in very poor condition may not stop leakage even though the nuts are pulled up to the breaking point. If a gasket is torn or burned across an area that must be sealed, it should be renewed. Gaskets should be removed and renewed in accordance with the engine manufacturer's instructions.

Gaskets may also be damaged by tightening the nuts unevenly or insufficiently. Figure 8–12 illustrates a condition that may occur if the nuts are tightened unevenly. That portion of the gasket below the tight nuts may become pinched or cut, particularly where the mating surfaces or the head and cylinder block are not perfect planes.

If the nuts are not tightened to the specified torque wrench reading, the gasket may not be compressed sufficiently to cause it to conform to the irregularities in the

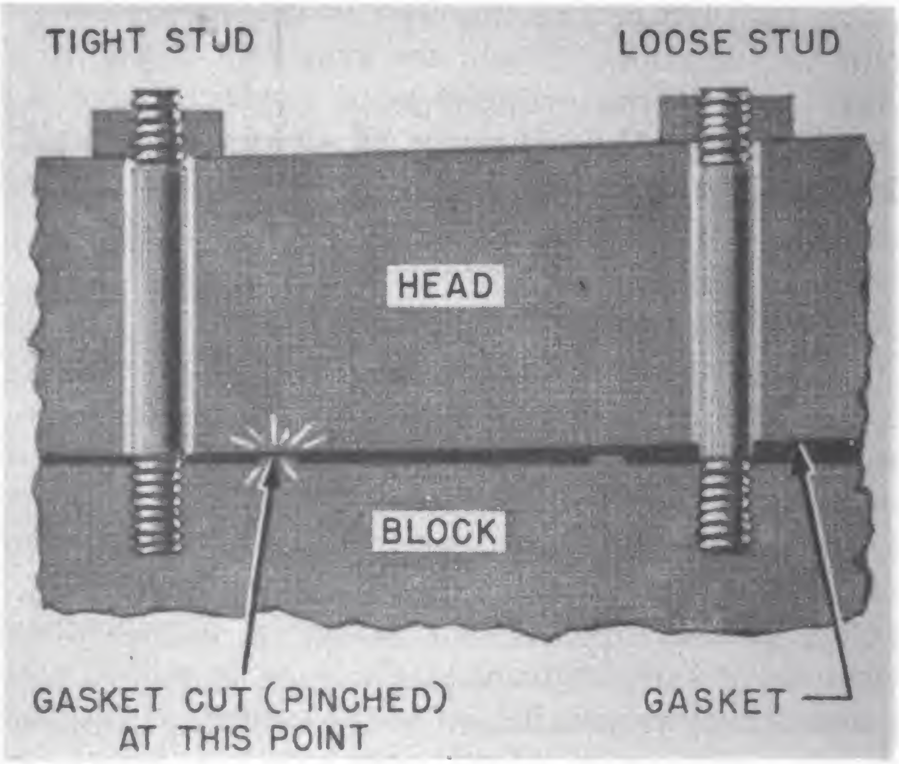


Figure 8–12.—Effect of uneven tightening on a gasket.

machined surfaces. This will prevent proper sealing and allow blow-by of the combustion gases, burning of the gasket material, and may result in complete failure of the gasket.

When pushing a gasket over the studs, care must be taken NOT to bend, tear, or break the gasket. In some installations, however, the gaskets do not surround the studs but can be placed in recesses either in the cylinder block or the cylinder head. In such cases, the gasket must be positioned properly in the recess to avoid cutting or pinching it when the head is pulled down (fig. 8–12). In addition, it is important that the correct type of gasket be used; a gasket of improper dimensions may prevent proper sealing of the cylinder head on the cylinder block, and result in stud breakage as well as burned surfaces.

PISTONS AND CONNECTING ROD ASSEMBLIES

Assemblies of this nature may have the trunk-type or the crosshead-type pistons. Since the majority of en-

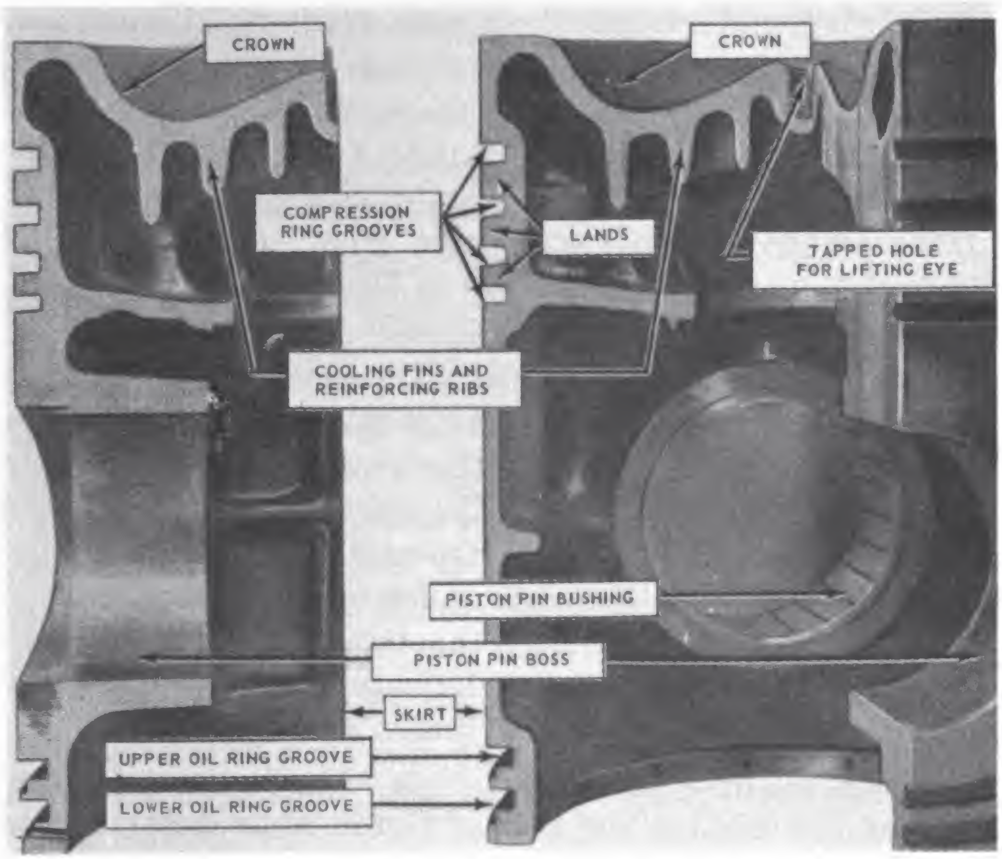


Figure 8–13.—Typical trunk-type piston.

gines in use by the Navy have trunk-type pistons, and since the troubles encountered with cross head pistons are very much the same as those of the trunk type, only the latter type will be discussed in this section. A typical trunk-type piston is illustrated in figure 8–13.

Pistons

Trunk-type pistons are subject to such forces as gas pressure, side thrust, inertia, and friction. These forces, together with overheating and the presence of foreign matter, may cause such troubles as undue piston wear, crown and land dragging, cracks, piston seizure, clogged oil holes, and piston pin bushing wear.

EXCESSIVE PISTON-TO-LINER CLEARANCE.—Symptoms of excessive clearance between a piston and cylinder are

piston slap and excessive oil consumption. Piston slap occurs just after top dead center and bottom dead center, as the piston shifts its thrust from one side to the other. As the cylinder taper increases with wear, oil consumption increases. Since taper causes the rings to flex on each stroke of the piston, excess ring wear occurs, allowing lube oil to pass and be burned in the cylinder. This results in the accumulation of excessive carbon deposits.

CROWN AND LAND DRAGGING.—Pistons and liners may become sufficiently worn to permit the piston to cock over in the cylinder. This allows the crown and ring lands to drag on the cylinder wall. The results of dragging can be determined by visually inspecting the parts of the piston in question. However, most of the pistons now in use in the Navy are free from this trouble, since the crown and ring lands are of smaller diameter than the skirt, and therefore do not contact the cylinder wall.

PISTON WEAR.—Although piston wear is normal in all engines, the amount and rate of piston wear depend upon several controllable factors. (The causes of excessive piston wear, and crown and land dragging, are also the causes of other piston troubles.)

One of the controllable factors is LUBRICATION. An adequate supply of oil is essential to provide the film necessary to cushion the piston and other parts within the cylinder and prevent metal-to-metal contact. Inadequate lubrication will not only cause piston wear and crown and land dragging, but may also cause piston seizure, and piston pin bushing wear.

Lack of lubrication is caused either by a lack of lube oil pressure or by restricted oil passages. The pressure-recording instruments usually give warning of low oil pressure before any great harm results. However, clogged passages offer no such warnings, and their discovery depends upon the care that is exercised in inspecting and cleaning the piston and connecting rod assembly.

Another controllable factor which may be directly or

indirectly responsible for many piston troubles is IMPROPER COOLING WATER TEMPERATURES.

If an engine is not operated within the specified temperature limits, lubrication troubles will develop. High cylinder surface temperatures will reduce the viscosity of the oil. As the cylinder lubricant thins, it will run off the surfaces. The resulting lack of lubrication leads to excessive piston and liner wear. However, if temperatures are below those specified for operation, viscosity will be increased, and the oil will not readily reach the parts requiring lubrication.

Oil plays an important role in the cooling of the piston crown. If the oil flow to the underside of the crown is restricted, deposits caused by oxidation of the oil will accumulate, lowering the rate of heat transfer. Therefore, the underside of the piston crown should be thoroughly cleaned whenever pistons are removed.

While insufficient and uneven cooling may cause ring land failure, excessive temperatures may cause piston seizure; an increase in the rates of oxidation of the oil, resulting in clogged oil passages; or damage to piston pin bushings.

Seizure or excessive wear of pistons may be caused by IMPROPER FIT. New pistons or liners must be installed with the piston-to-cylinder clearances specified in the manufacturer's instruction manual. If clearance is insufficient, a piston will not wear in; instead the piston will probably bind, with resulting excess surface temperatures that may lead to seizure or breakage.

Binding increases wear and shortens piston life by scuffing the liner or galling the piston skirt and crown. Scuffing roughens the liner so that an abrasive action takes place on the piston skirt, generating additional heat which may distort or crack the piston or liner. Galling, especially on aluminum pistons, causes the metal to be wiped in such a manner that the rings may bind in the grooves.

A loose-fitting piston may be just as destructive as one which is too tight. A loose piston may result in dragging of the crown and cocking of the piston, which may, in turn, result in broken or cracked ring groove lands.

When pistons are removed, the area above the compression rings should be inspected for signs of dragging. Causes of dragging must be determined and remedied. However, make certain that the trouble is dragging of the piston crown and not the accumulation of carbon deposits on the surface. The cause of cocking (which allows the crown to drag) is usually a worn liner, or a combination of a worn piston and liner.

Excessive wear on the piston and piston pin bushing may result from an OVERLOAD or from an UNBALANCED LOAD. Overloading an engine increases the forces on the pistons and subjects them to higher temperatures, thus increasing the rate of wear. There should be a load balance on all pistons at all times. Balance of an engine can be determined by checking the pyrometers, the rack settings, and the firing and compression pressures.

Cracking of the lands of a piston may result if there is INSUFFICIENT RING GROOVE CLEARANCE. For correct piston ring operation, proper clearance must be maintained between the ring and the land, and also between the ends of the ring. This is necessary so that the ring may be free to flex at all operating temperatures. The clearance depends upon the size of the ring and the materials involved.

After installing a piston ring, check the clearance between the ring and the land. This check is made with a thickness gage, as shown in figure 8–14, and must be made completely around the piston.

In most cases, damaged or excessively worn pistons have to be replaced. Processes such as metal spray or plating have been developed for rebuilding or resizing worn pistons, but this type of work is generally accomplished at engine salvage centers. Since replacement of

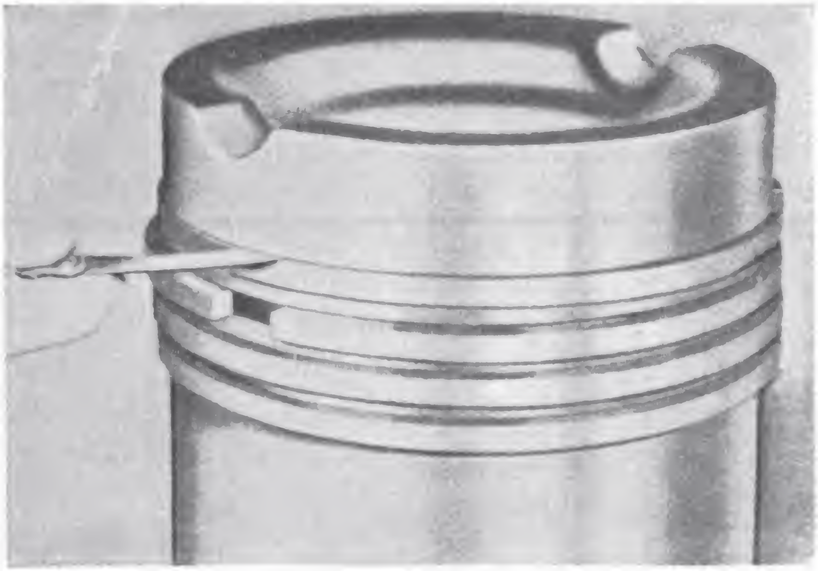


Figure 8–14.—Checking ring groove side clearance.

damaged pistons is generally necessary, shipboard spares should be maintained at full allowance.

Piston Rings

EXCESSIVE WEAR, STICKING, AND BREAKAGE.—The troubles to which piston rings are subject, as well as the symptoms and causes, are shown in figure 8–15. All symptoms and causes shown for ring wear are either directly or indirectly related to other ring and piston troubles. In addition to symptoms and causes of piston ring troubles, other factors are listed that may be responsible for low compression or for excessive oil consumption.

When a cylinder with a low compression pressure is located, the possibility of the cause being some factor other than excessive wear should be eliminated before disassembly or replacement of piston rings is attempted. Of the causes listed in figure 8–15 under "other factors which may cause low compression," a, b, c, d, and e are causes that would affect the pressure in only one cylinder assembly of a multi-cylinder engine, while f, g, and h are causes affecting a group of cylinders, or possibly all cylinders. Therefore, when symptoms indicate com-

EXCESSIVE WEAR	STICKING	BREAKAGE
A. Symptoms: 1. Low compression 2. Hard starting 3. Loss of power 4. Smoky exhaust 5. Waste of fuel 6. Excess oil camsumption 7. Poor engine operation (Other factors which may cause low compression pressure: a. Leaking cylinder valves b. Faulty injector gasket c. Faulty head gasket d. Leaking after-chamber valves e. Clogged intake ports f. Intake air header leakage g. Faulty blower h. Clogged air filter (Other factors which may cause excessive oil consumption: a. Loose bearings b. High lube oil temperatures c. Oil line leakage d. Improper oil)	C. Symptoms: 1. Low compression 2. Loss of power 3. Smoky exhaust 4. Excessive oil consumption 5. Blow-by forcing fumes from crankcase	E. Symptoms: 1. Hard starting 2. Loss of power 3. Excess oil consumption 4. Possible emission of smoke from crankcase breather
B. Causes: 1. Inadequate lubrication 2. Excessive piston heat 3. Rings damaged during installation 4. Ring-to-land clearance insufficient 5. Dust or dirt in intake air 6. Dirt in lube-oil or fuel 7. Rings stuck in grooves 8. Worn cylinder liners	D. Causes 1. Improper ring-to-land clearance 2. Insufficient ring pressure 3. Excessive operating temperature 4. Improper oil 5. Improper installation	F. Causes: 1. Cylinder liner ridge 2. Cylinder port damage 3. Insufficient gap clearance 4. Insufficient clearance behind ring

Figure 8–15.—Piston ring troubles, their symptoms and causes.

pression wear, it is advisable to first consider other possibilities. Excessive oil consumption is generally associated with worn oil rings, but there are other factors which may cause abnormal oil usage, and these should be checked before replacement of oil rings is undertaken.

Since the causes and prevention of piston ring troubles are closely related, the discussion in this section will deal with each cause, and its prevention, as it might apply to all ring troubles. Some of the causes listed in B, D, and F of figure 8–15 have already been discussed as they affect other parts of a piston assembly and liner assembly; in many cases the information given earlier is also applicable to the piston ring.

Oxidation of the lube oil, leaving carbon deposits on the rings and in the grooves, is caused by EXCESSIVE OPERATING TEMPERATURES. The carbon limits movement and expansion of the rings, preventing them from following the cylinder contour and sealing the cylinder. Sticking, excessive wear, or breakage may result.

Since INSUFFICIENT RING GROOVE CLEARANCE can cause the rings to stick, proper clearance must exist between the ring and land as well as behind the ring. It is not the function of the rings to support or position the piston in the cylinder bore, but if proper clearance does not exist, the rings are likely to become loaded by inertia forces, and by side thrust on the piston. These forces should be borne solely by the skirt of the trunk-type pistons.

Some of the factors that cause improper ring clearance are:

1. Abnormal carbon deposits on rings and in grooves. Carbon deposits will occur, to some degree, in most engines. When replacing rings, clean the grooves thoroughly; carbon deposits interfere with new rings.
2. Improper dimensions. New rings must have the proper thickness, width, diameter, and gap. The correct values for a particular engine can be obtained from the instruction manual.

One cause of undue loads on a ring is INSUFFICIENT GAP CLEARANCE. This causes the ring to be forced out and into a port of a ported cylinder. A bright spot found on each end of a broken ring indicates insufficient gap clearance. When new rings are installed, all measurements of gap and side clearance should be recorded on applicable Unit Record Card. Sufficient gap clearance must exist at both the top and the bottom of the cylinder bore.

Sticking and binding may result from INSUFFICIENT RING PRESSURE. The tendency of the ring to return to its original shape pushes it against the cylinder wall, and makes the initial seal. The pressure of the combustion gases reinforces this seal. Extended use and overheating may weaken rings to the point where they do not seat properly, and the rings are then likely to bind in the groove. A check of the free gap for a piston ring will indicate the ring's condition with respect to sealing qualities. If the instruction manual does not give a prescribed dimension for free gap, compare the gap with that of a new ring.

Conditions which cause piston rings to stick in the grooves, wear excessively, or break are often the result of IMPROPER LUBE OIL. Some lube oils cause a resinous gumlike deposit to form on engine parts. This can be avoided by using Navy-approved oils.

Probably the chief factor affecting the wearing of piston rings is a WORN CYLINDER LINER. Therefore, when new rings are installed, surface conditions, amount of taper, and out-of-roundness of the liner must all be considered. By placing the ring gaps above the piston pin bosses, the ring is in the best position to make allowance for cylinder wear. Gaps of adjacent rings should be staggered 180° to reduce gas leakage. Rings having angle gaps should be positioned so that the slope of the gaps on adjacent rings will be in alternate directions.

With the wearing away of material near the top of a cylinder liner, a ridge will gradually be formed. When a piston is removed, this ridge must also be removed, even

though it has caused no damage to the old set of rings. The new rings will travel higher in the bore by an amount equal to the wear of the old rings, and the replacement of the connecting rod bearing inserts will also increase piston travel. As the top piston ring strikes the ridge, because of this increase in travel, breakage of the ring and perhaps of the land is almost certain.

MAINTENANCE AND REPLACEMENT OF PISTON RINGS.—While stuck rings may be freed and made serviceable, excessively worn or broken rings must be replaced with new ones. The installation of a new set of rings in an engine is a job that requires great care. Damage generally occurs when the rings are being placed in the grooves of a piston, or when the piston is being inserted in the cylinder bore.

Care must be taken when the piston and connecting rod are being removed from the cylinder. In most engines, the piston should not be removed from a cylinder until the cylinder surface above the ring travel areas has been scraped. In addition to removing all carbon, the lip of any appreciable ridge must be removed before removing the piston. Do not remove a ridge by grinding, as this will allow small abrasive particles from the stone to enter the engine. A metal scraper should be used, and a cloth placed in the cylinder to catch all metal cuttings. The lip of a cylinder ridge can generally be removed by scraping sufficiently to allow the piston assembly to slide out of the liner. After the piston has been removed, a more detailed inspection of the ridge can be made.

Finish scraping the remaining ridge but be careful not to go too deep. Finish the surface with a handstone. In extreme cases, it may be necessary to remove the liner and use a small power grinder to remove the ridge.

After the piston and connecting rod have been removed, check the condition and wear of the piston pin and piston pin bushing, both in the piston and in the connecting rod.

Removal and installation of piston rings can be best

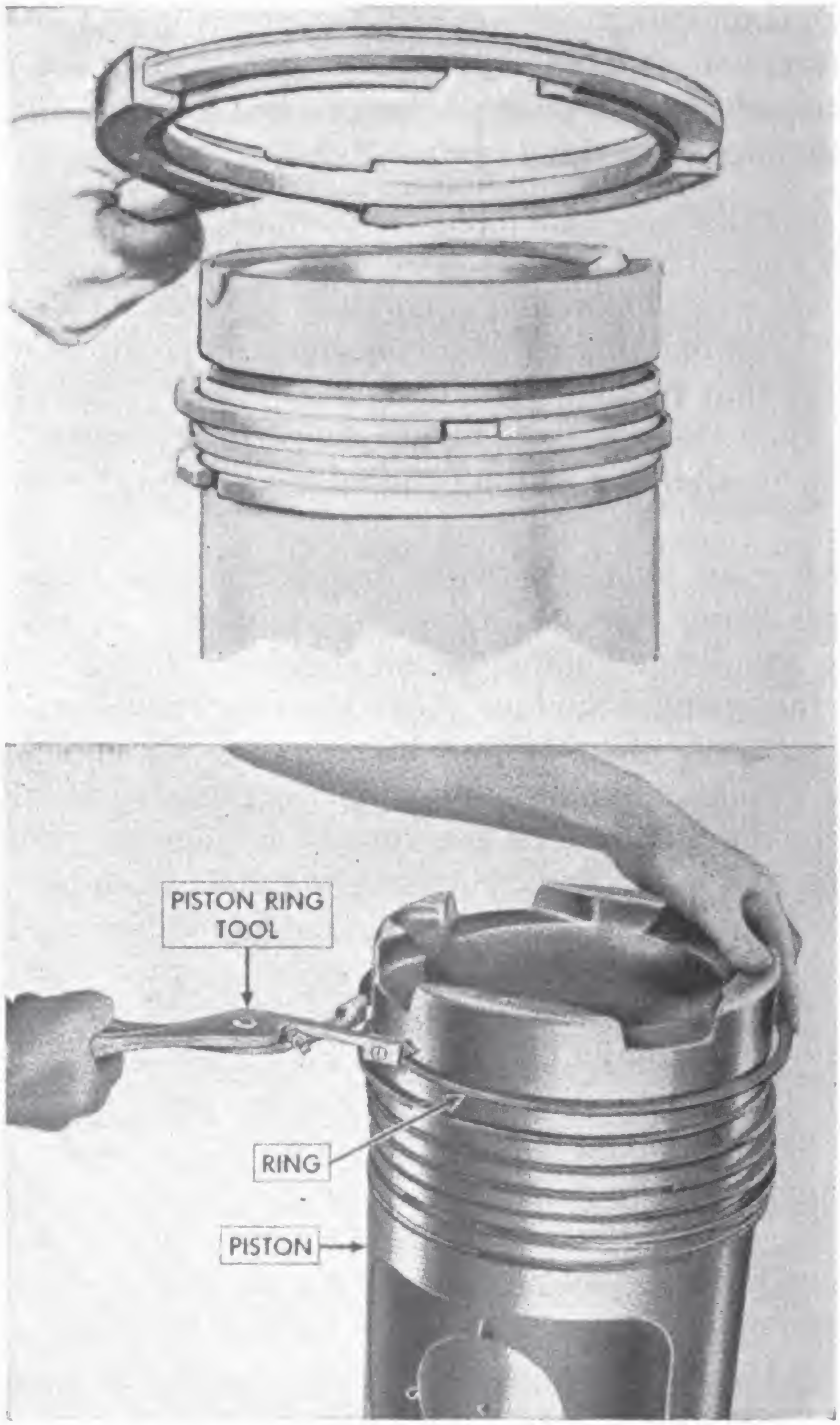


Figure 8–16.—Piston ring tools used for removal or installation.

accomplished with a tool similar to those shown in figure 8–16. These tools generally are provided with a device which limits the amount that the ring can be spread, and prevents the rings from being deformed or broken.

If a ring is securely stuck in the groove, additional work will be necessary. It may be necessary to soak the piston overnight in an approved cleaning solvent or in Diesel oil. If soaking does not free a stuck ring, it will be necessary to drive the rings out with a brass drift. The end of the drift should be shaped and ground in a manner that permits use without damaging the lands.

After the rings have been removed, the piston is thoroughly cleaned, and special attention should be given to the ring grooves. (Diesel oil or kerosene are satisfactory cleaning agents.) In addition, it may be necessary to clean excessive deposits from the oil return holes in the bottom of the oil control ring grooves. This can be accomplished with a twist drill of a diameter corresponding to the original size of the holes.

Another complete inspection follows the cleaning of the piston. All parts are checked for any defects which would require replacement of the piston. Particular attention should be given to the ring grooves, especially if the pistons have been in service for a long period of time. A certain amount of enlargement of the width of the grooves is normal, and SHOULDERING of the groove may occur. Shouldering, as illustrated in figure 8–17, results because of the "hammering out" motion of the rings. The radial depth of thickness of the ring is much less than the groove depth, and while the ring wears away an amount of metal corresponding to its own width, the metal at the bottom of the groove remains unchanged. Shouldering usually requires replacement of the piston, since the shoulders prevent the proper fitting of new rings.

After determining that a piston is serviceable, inspect the rings carefully. Any burrs on new rings may be removed with a flat file. The ring is then inserted in the

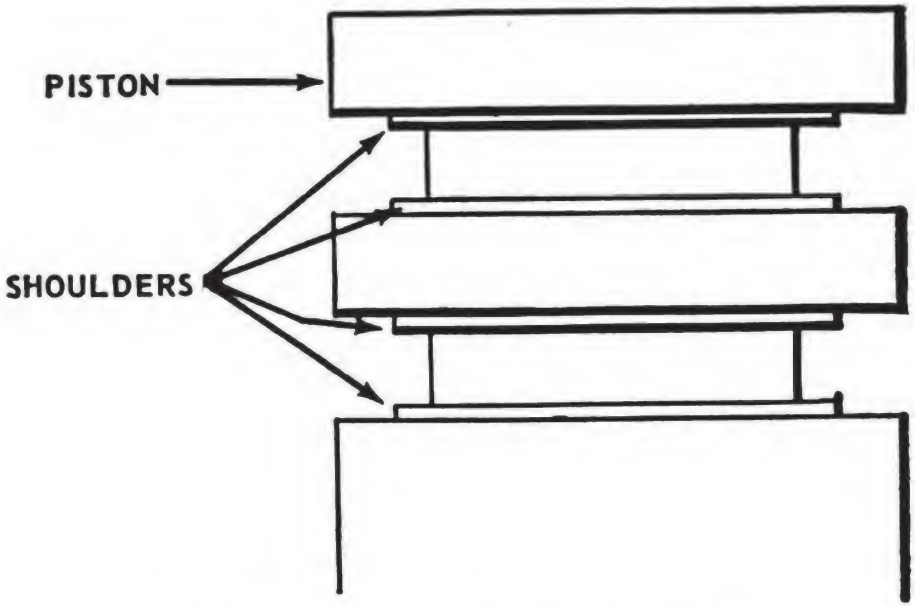


Figure 8–17.—Ring groove shoulders due to wear.

cylinder bore below the upper point of ring travel, and leveled with the aid of a piston. (In figure 8–18, A illustrates the use of an inverted piston to level a piston ring.) Measure the gap clearance (fig. 8–18B), which should be within the limits specified in the manufacturer's instruction manual. After determining the gap at the top of

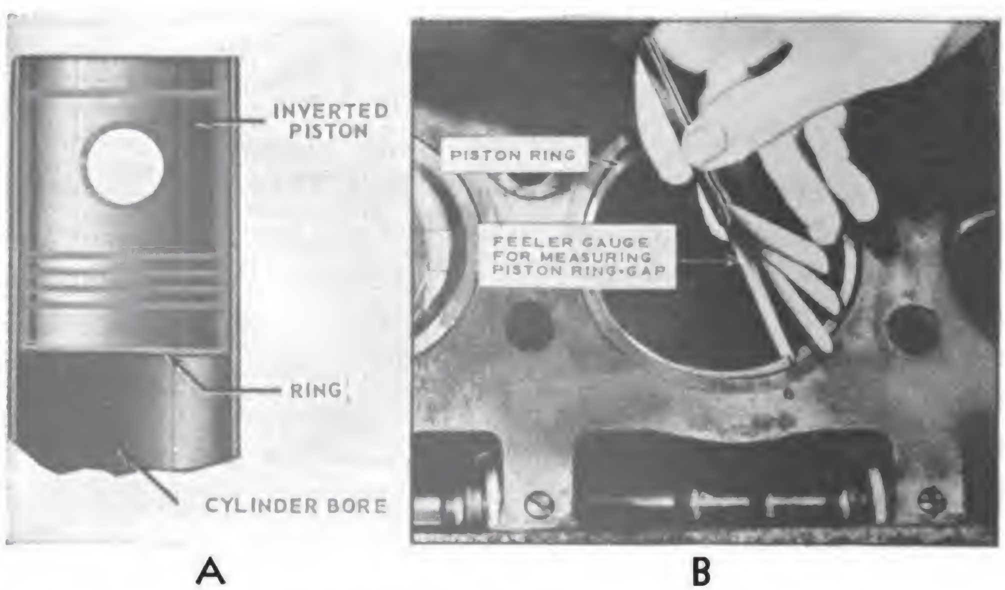


Figure 8–18.—Leveling a piston ring (A) and measuring ring gap clearance in the cylinder bore (B).

the bore, push the ring to the bottom to a point within the lower travel of the ring, and measure the gap again. If the gap is less than specified, the ends of the ring will have to be filed with a straightcut mill file until the proper gap is obtained.

A liner may have a slight amount of taper which results from wear. In such cases, the gap may decrease as the ring is moved from the top to the bottom of the cylinder. However, the ring gap should never be less than the minimum value specified. Ring gap may be measured by placing the ring in a liner, or in a ring gage, or by using a ring compressing tool to hold it in place on the piston; the gap measurement is then taken with a feeler gage, as shown in figure 8–19. If the ring gap measurement is

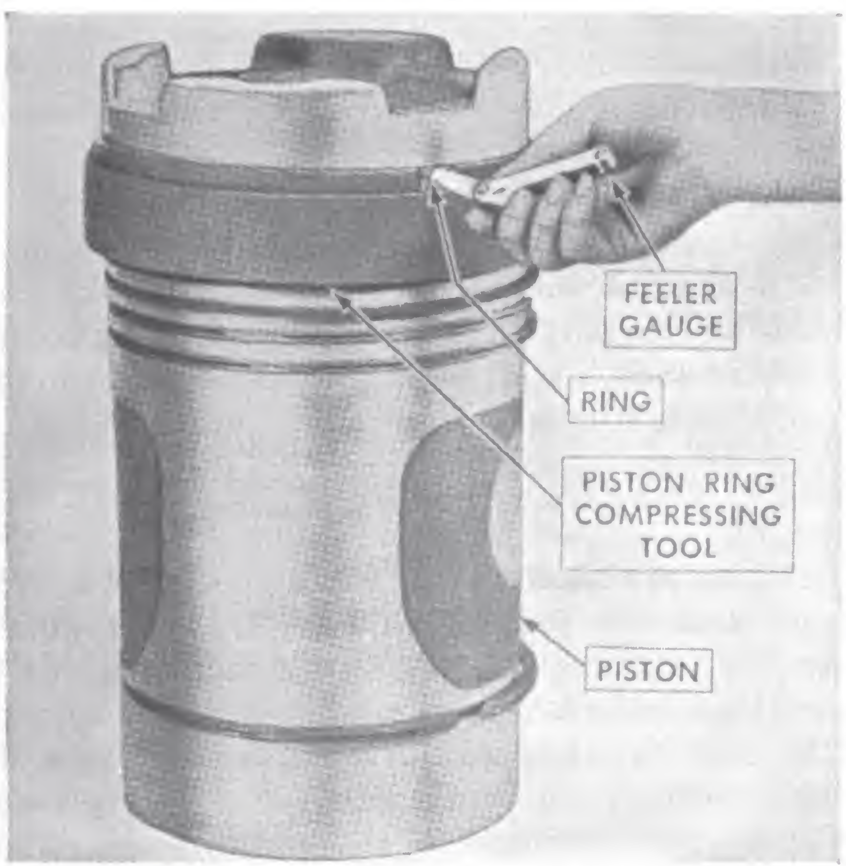


Figure 8–19.—Checking ring gap clearance.

made with the ring on the piston, it is first necessary to measure the piston for wear and out-of-roundness.

After the proper gap clearance has been determined, the piston pin and connecting rod can be reinstalled. During reassembly and installation of a piston and connecting rod assembly, all parts should be well lubricated. The rings can be installed on the piston with tools similar to those used for removal. When installing piston rings, spread them as little as possible; this avoids breaking of rings. The lowest ring should be inserted first. When all the rings have been installed, check the ring-to-land clearance as indicated in figure 8–14.

After all the rings have been properly installed, the entire assembly should be coated with oil then inserted in the cylinder bore. Rings should be positioned so that the gap of each successive ring is on an alternate side and the gaps in line with the piston pin bosses. Care must be exercised in handling an oiled piston assembly; otherwise the piston may be dropped. On large engines, a chain fall should be used to hold the piston assembly in position as it is being lowered into the cylinder.

When a piston is being inserted into a cylinder, piston rings must be compressed evenly. Special funnel-type tools, similar to the one shown in figure 8–20, are usually provided for this purpose. Other types of ring compressing tools include a steel band that is placed around the ring and so constructed that it can be tightened.

Piston Pins and Pin Bearings

Piston pins are constructed of hardened steel alloy, and their surfaces are precision finished. These pins and the pin bearings require very little maintenance; total failure seldom occurs.

Of the two types of piston pin bearings (the sleeve bushing and the needle bearing), the needle type requires considerably less clearance for correct lubrication and operates with far less friction. However, these advantages

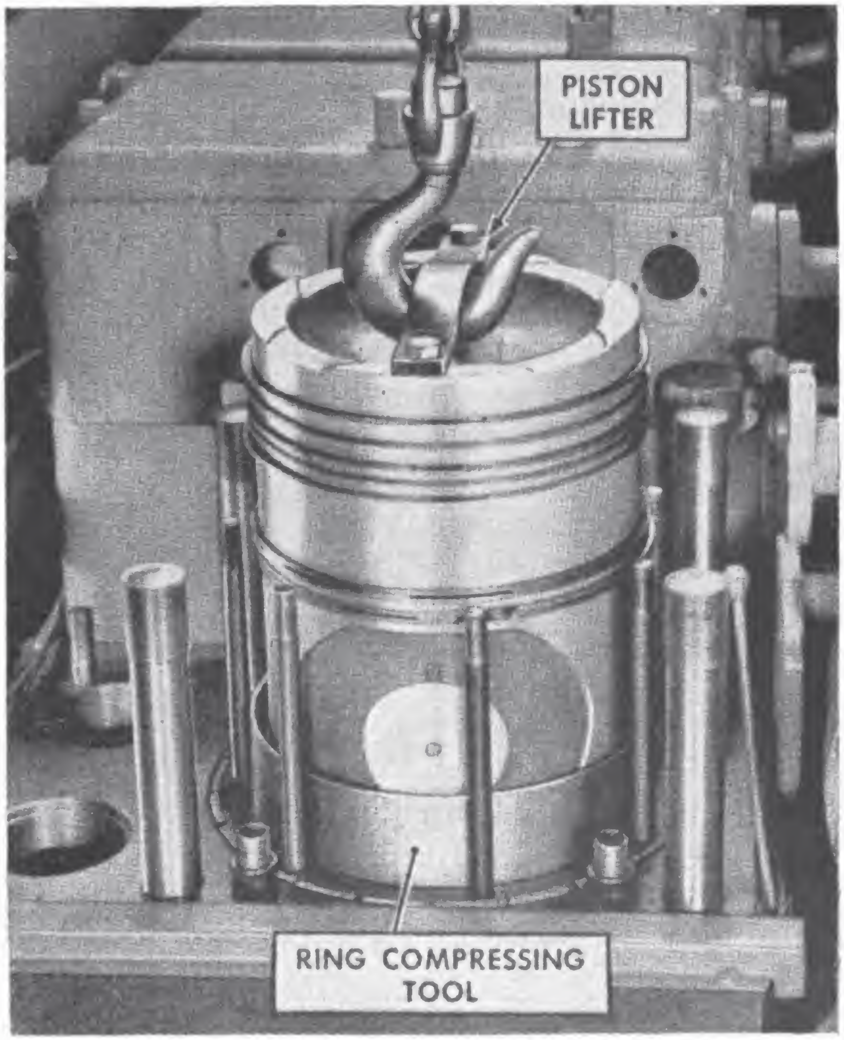


Figure 8–20.—Installing a piston in a cylinder bore with funnel-type ring compressor.

are offset by a higher cost and a shorter service life as compared with the bushing type. The greater clearance necessary in the bushing type bearing often leads to pounding, as the pin and bushing become worn. Most troubles experienced with needle bearings result from improper assembly and installation.

The troubles generally encountered with piston pins and piston pin bearings are WEAR, PITTING, and SCORING.

Wear of a pin, bushing, or needle bearing is normal, but the rate of wear can be unnecessarily increased by such factors as inadequate and improper lubrication, over-

loading misalignment of parts, or the failure of adjacent parts.

Every time a piston assembly is removed from an engine, it should be inspected for wear. Piston pins and bushings should be measured with a micrometer, as shown in figure 8–21, to determine if wear is excessive. Areas that do not make contact must be avoided when measur-

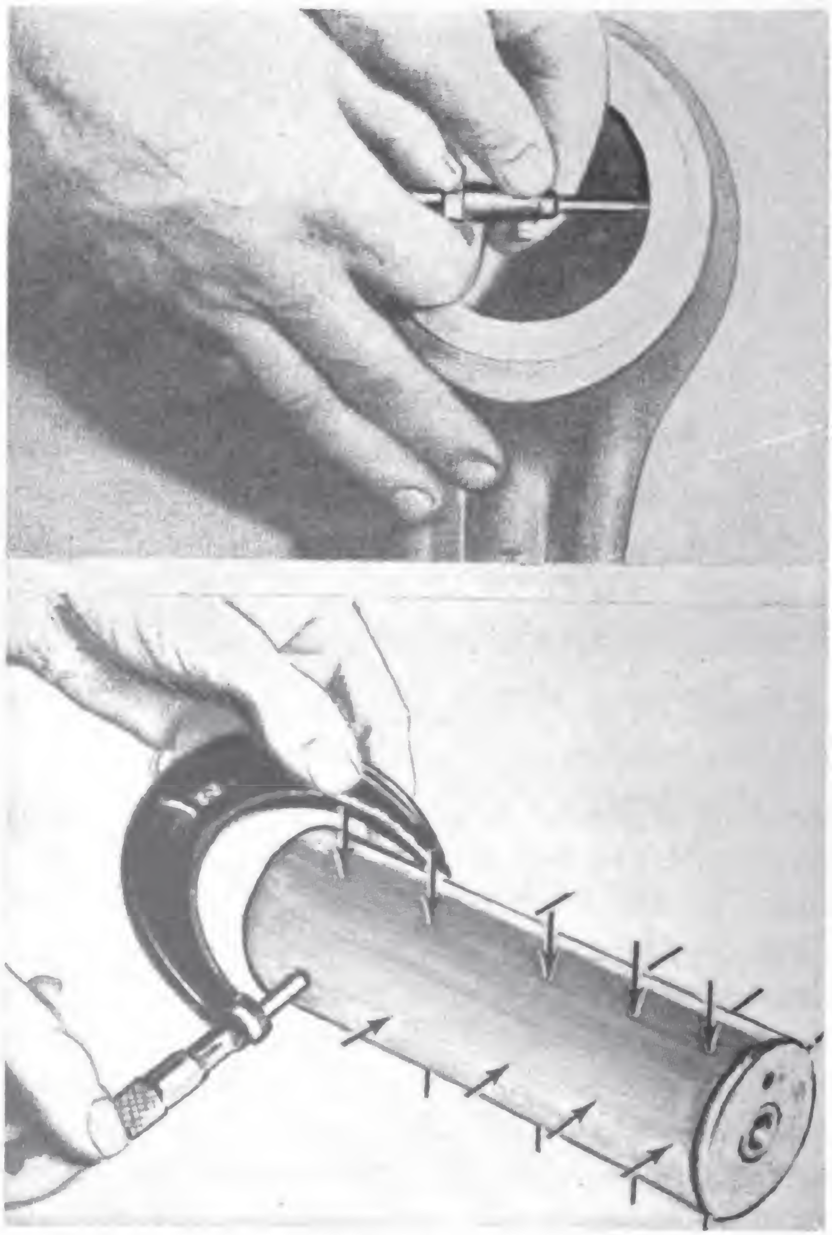


Figure 8–21.—Measuring piston pin and piston bushing for wear.

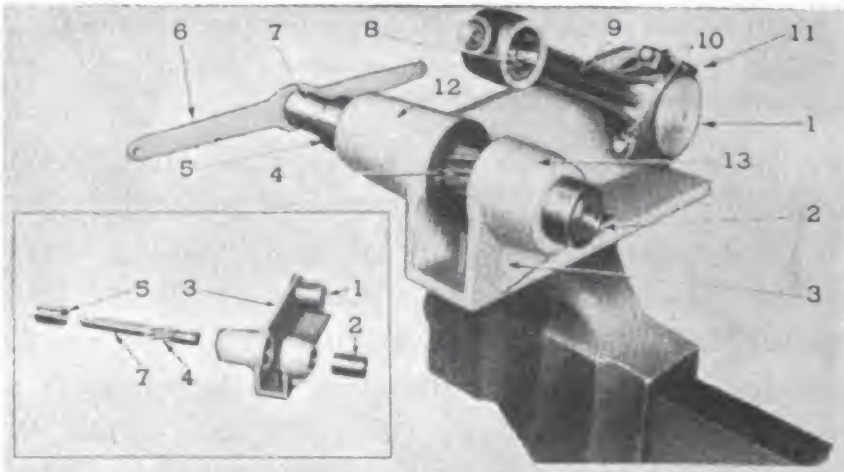
ing. Such areas include those between the connecting rod and piston bosses, and areas under the oil holes and grooves.

Worn needle bearings can be located, during engine overhaul, by measuring the diameter of individual needles with a micrometer. The correct and limiting valves of the needle diameters may be obtained from the instruction manual for the particular engine.

Excessive wear of pins, bushings, or bearings is often the result of INSUFFICIENT OR IMPROPER LUBRICATION. (These parts are usually pressure lubricated.) The failure of a pressure lubricating system is usually detected before piston pins, bushings, or bearings are seriously damaged. Insufficient lubrication of these parts is usually caused by obstructions (lint, carbon, dirt, or paper toweling) caught in the oil passages of the connecting rods. If the bushings have been so installed that the oil holes do not line up, lubrication may be restricted. This misalignment of oil holes may also result from a bushing coming loose and revolving slightly out of position. Interchanging the upper and lower connecting rod bearings on some engines may prohibit the flow of oil to the upper end of the rod. Refer to the specific manufacturer's instruction book for information on the interchangeability of parts.

Dirty lube oil and the resulting abrasive action on bearings not only cause excessive wear but may also cause pitting. Abrasive particles in oil are more detrimental to needle type bearings than to the journal bearing because a needle bearing is incapable of embedding such foreign matter.

Rapid wear of piston pins and bearings is certain to occur if the engine is OVERLOADED, and such wear may lead to the surface pitting of the pin. Because of the small area of contact, the unit load of a needle bearing is very great; overloading the engine materially increases the high unit load, and causes excessive wear.



1. Arbor.
2. Guide Bushing—Rear.
3. Body.
4. Flutes (Cutting Edges).
5. Guide Bushing—Front.
6. Handle.
7. Reamer.
8. Piston Pin Connecting Rod Bushing.
9. Connecting Rod.
10. Connecting Rod Bolt.
11. Connecting Rod Cap.
12. Front Guide Boss.
13. Rear Guide Boss.

Figure 8–22.—Reaming equipment.

Uneven loading on piston pins and bearings will result if there is MISALIGNMENT OF THE CONNECTING RODS. A misaligned rod is usually indicated by uneven wear of the piston pin and bushing, and piston skirt wear. Misalignment may be the result of the rod being bent, or more often, the result of improper reaming of the bushing for proper clearance. Figure 8–22 shows equipment used for reaming a bushing.

Surface pitting and scoring of piston pins result when NEEDLE BEARING FAILURES occur. This surface disintegration of the pin occurs more frequently when needle bearings are used. (The high unit loading of this type bearing tends to cause failure of the needles.) Once the needle surfaces start to disintegrate, it is only a short time until the surface of the pin begins to fail.

Do not interchange individual needles of one set with those of another set. The overload caused by differences in needle diameter will result in early failure of an entire needle bearing assembly. The defective parts (piston

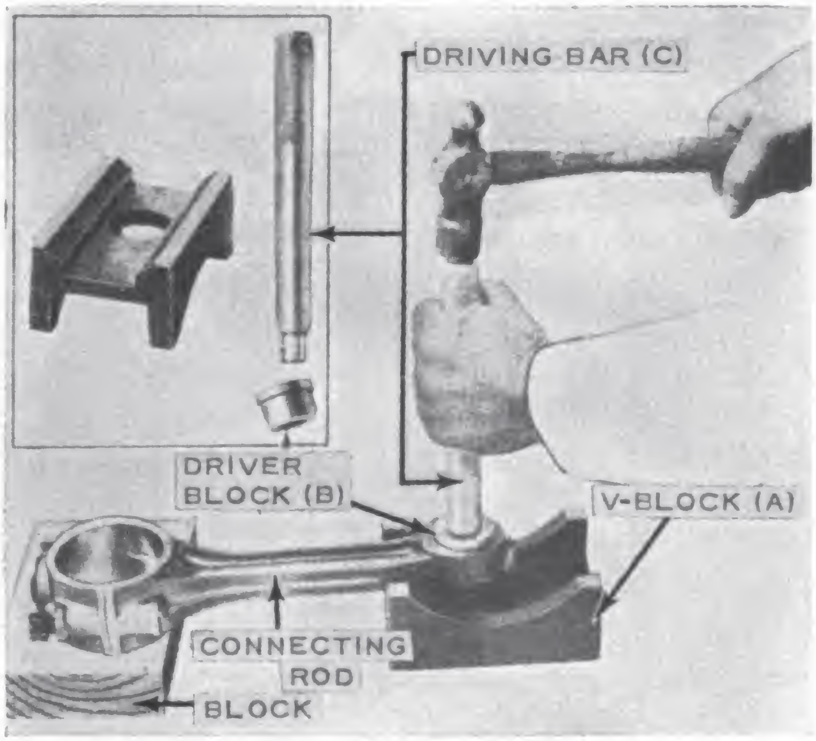


Figure 8–23.—Removing or installing a piston pin bushing.

pins, bushings, or needle bearings) should be replaced when surface disintegration occurs, or when wear has reached the maximum permissible limit.

Bushings may be pressed out of the rod with a mandrel and an arbor press, or with special tools as shown in figure 8–23. It is also possible to remove bushings by first shrinking them with dry ice. The use of dry ice will also facilitate the insertion of the new bearing.

When new bushings are inserted, the bore into which they are pressed must be clean, and the oil holes in the bushing and the oil passages in the rod must be aligned. Sometimes a piston pin bushing will have to be reamed after it has been installed in order to obtain the proper clearance. After a new bushing has been installed, it is advisable to check the alignment of the rod with such equipment as illustrated in figure 8–24. The instruction manual should be consulted for details concerning clearances and alignment procedures.

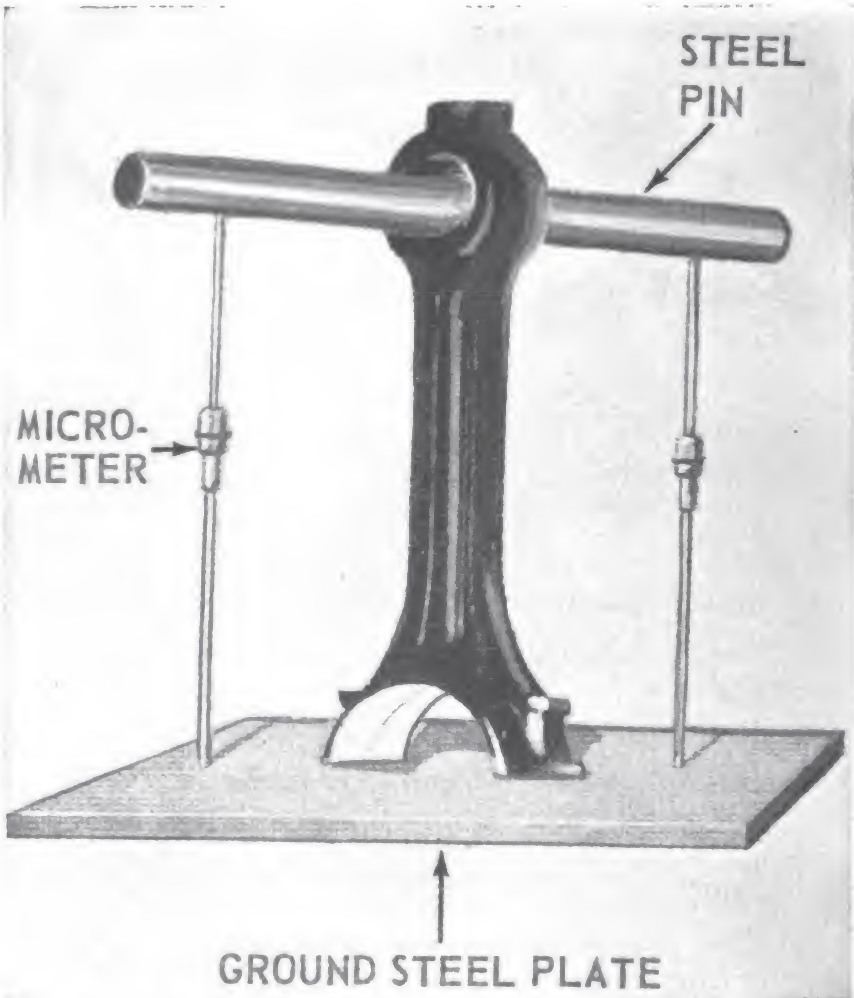


Figure 8–24.—Checking alignment of a connecting rod.

Connecting Rods

Most connecting rod troubles involve either the connecting rod bearing or the piston pin bearing. Connecting rod troubles can generally be avoided by performing proper maintenance procedures and by following instructions in the manufacturer's booklet. However, there are exceptions, such as the cracking of connecting rods which results from defective material.

It is extremely important to discover cracks before they develop to a point where failure of the rod occurs. Most rod cracks are not visible unless some special aid is used

during the inspection. The use of magnetic flux is considered the best method of locating cracks. The rod is strongly magnetized and then dusted with a magnetic powder. The powder may be applied as a mixture with kerosene. The powder concentrates on the magnetic lines of force which veer away from, and do not cross, the crack. Hence, the powder makes a distinct pattern around the crack and shows where it is located.

Repair of connecting rods which are bent or cracked should not be attempted. The rods should be replaced. No chances should be taken with a defective rod because serious damage will result if breakage occurs during operation.

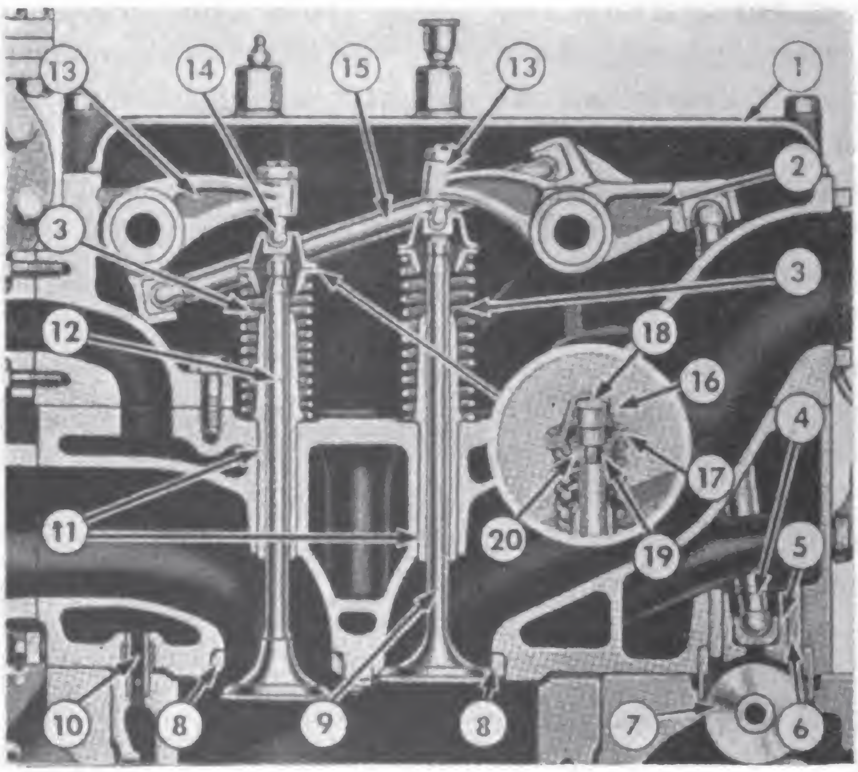
Repair of defective connecting rod bolts should not be attempted, except for the removal of small burrs. These can be removed from the threads with a fine triangular file. When there is doubt as to the condition of a bolt or a nut, it must be replaced. It is advisable that both the nut and bolt be replaced at the same time. New cotter keys, when applicable, should always be used when installing rod bolts.

Out-of-roundness of a connecting rod bore may be determined with an inside micrometer (fig. 8–8). The cause of any out-of-roundness must be determined, and the necessary correction made. Then the bore should be rechecked. If permanent distortion exists, the rod must be replaced.

Plugged oil passages of connecting rods can be made serviceable by running a wire through any passage that shows indications of being plugged. In extreme cases, it may be necessary to drill the passages free of foreign matter.

ENGINE VALVE GEAR

The valve gear of different engines may vary considerably in construction and design, even though the function remains the same. Comparison of the two valve gear assemblies shown in figures 8–25 and 8–26 show



1. Cover	11. Valve Stem Bushing
2. Bell Crank	12. Exhaust Valve
3. Spring	13. Rocker Arm
4. Push Rod	14. Tappet Screw
5. Crosshead	15. Intermediate Push Rod
6. Crosshead Guide	16. Tappet Bearing Retainer
7. Cam Follower	
8. Valve Seat Insert	17. Spring Retainer
9. Intake Valve	18. Tappet Bearing
10. Ferrule	19. Valve Keeper

20. Keeper Retainer

Figure 8–25.—Valve gear of a Cooper-Bessemer GSB-8.

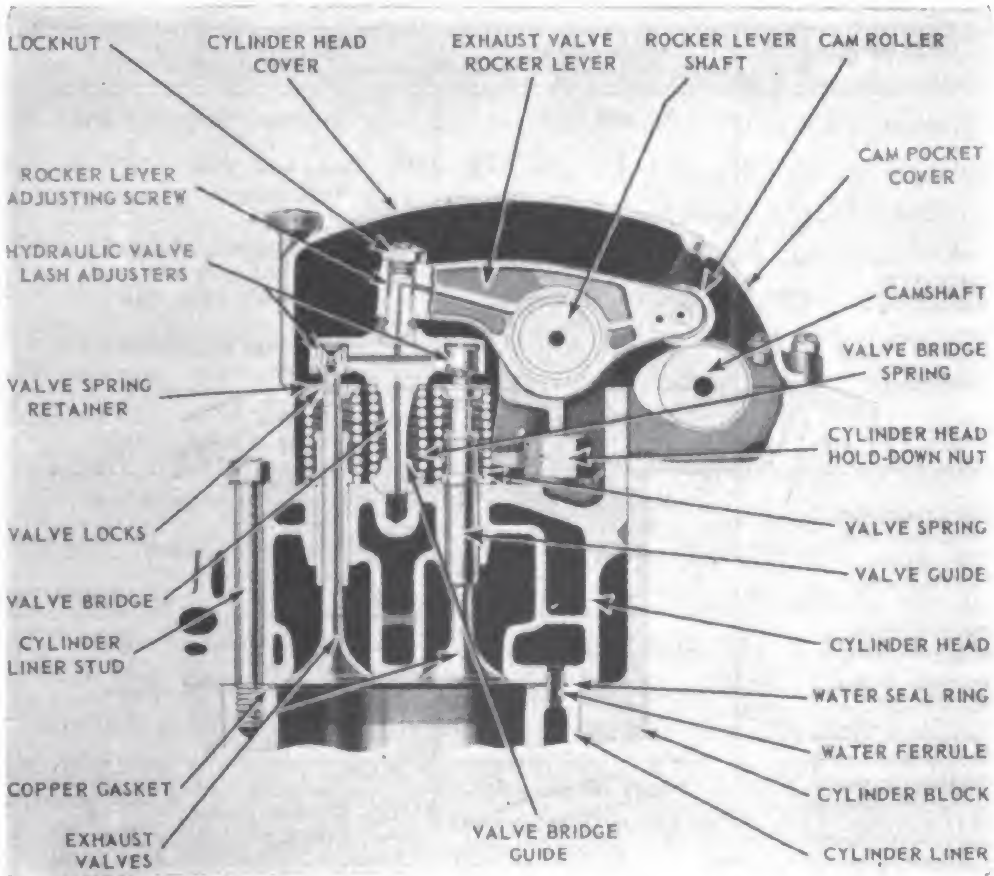


Figure 8–26.—Valve gear of a GM 278A.

several points of difference: hydraulic valve lash adjuster, valve keepers, push rods, cam followers, and rocker arms. Regardless of differences existing because of engine construction, there are certain valve gear troubles common to all applicable parts of valve gear assemblies. Figure 8–27 indicates these troubles, and their possible causes.

Valves

In internal combustion engines, the valve most commonly used as intake or exhaust valve is the poppet type. Intake valves generally give longer periods of trouble-free operation than do exhaust valves——the operating temperature of the intake valve is lowered by the air which enters the cylinder.

STICKING VALVES will cause an engine to misfire, and will produce unusual noises at the cam follower, push rod, and rocker arm. Improper lube oil or improper fuel will

VALVE GEAR	TROUBLE	POSSIBLE CAUSES
Valves	Sticking open	Resinous deposits from lube oil or fuel oil Bent valve stem Weak springs
	Burned valves	Carbon particles between seat and valve head Insufficient tappet clearance Valve head excessively reground
	Broken valve springs	Corrosion Fatigue of metal
	Worn valve keepers and retaining washers	Improper assembly or fit of valve caps Spacer shims omitted Use of improper parts
	Valve head broken off stem	Many causes, two general classes: Mechanical deformation Metal fatigue
Ports	Dirty and clogged	Excessive carbon deposits (Leaking blower shaft seal) (Worn oil rings)
Rocker arms	Worn bushing	Improper lubrications
	Excessive wear on pads and end fittings	Insufficient lubrication Excessive tappet clearance
	Tappet adjusting screw worn	Loose lock nuts
Push rods	Worn or loose end fittings	Improper tappet adjustment
Cam followers (roller type)	Worn roller surfaces	Fatigue of hardened surfaces
	Worn cam follower body and guide	Abrasive foreign material
	Worn roller needle bearings	Length of service
(mushroom type)	Worn surfaces	Stuck follower
Hydraulic valve lifter or lash adjuster	Noisy operation	Low oil pressure Ball check valve stuck Check valve seat scored Excessive leakage due to wear

Figure 8-27.—Valve gear troubles and their causes.

leave RESINOUS DEPOSITS which, if allowed to accumulate, may cause valves to stick.

If the resinous formation is slight, it can be removed by applying a half-and-half mixture of kerosene and lube oil to the valve stem and guide. Since any appreciable amounts of mixture settling in the cylinder could cause a serious explosion, caution must be exercised in using this mixture. (There are a number of Navy-approved commercial products that can be used when the gum deposits are slight, or when a complete disassembly is impracticable.)

A valve that hangs open not only prevents the cylinder from firing, but is likely to be struck by the piston and BENT so that it cannot seat properly. Symptoms of warped or slightly bent valves will usually show up in the form of damage to the surface of the valve head. To lessen the possibility of cylinder head valves being bent or damaged during overhaul, never place a cylinder head directly on a steel deck or grating; use a protective material such as wood or cardboard. Never pry a valve open with a screw driver or other tool.

Valves may close slowly, or fail to close completely, because of WEAK SPRINGS. At high speed, the valve gear may "float," thus reducing engine efficiency. Normal wear on valve springs is accelerated by excessive temperatures and by corrosion resulting from moisture combining with sulfur present in the fuel.

BURNED VALVES are indicated by irregular exhaust gas temperatures, and sometimes by an excessive exhaust noise. The principal causes of burned valves are carbon deposits, insufficient tappet clearance, defective valve seats, and valve heads that have been excessively reground.

The principal cause of burned exhaust valves is the lodging of small particles of carbon between the valve head and the valve seat. These particles come from the engine cylinder and head when deposits on those parts become excessive. The particles hold the valve open just

enough to allow the combustion gases to pass, or leak, at high velocities and temperatures. This combination causes the valve head to reach temperatures sufficiently high, which results in burning. The valve seat seldom burns under these conditions, because sufficient cooling is usually provided, by the jackets surrounding the seat, to keep the seat temperature below a dangerous point. The valve is generally cooled by several factors, including its contact with the valve seat. When carbon particles prohibit contact, the heat normally transferred from the valve head to the seat remains in the valve head.

When cleaning carbon from cylinder heads, see that all loose particles are removed from the crevices; extreme care must be taken to prevent the valve or seat from becoming nicked or scratched. Removing the valves from the engine will permit easier cleaning of the passages and facilitate removal of carbon deposits from the underside of the valve heads.

Tappet clearance adjustments should be checked at frequent intervals, to make certain that they are correct and that the locking devices are secure. The adjustment of valve clearances is discussed later in the chapter.

Most engines are equipped with valve seat inserts made of hard, heat-resisting, alloyed steel. Occasionally, a seat will crack and allow the hot gases to leak, burning both the insert and the valve. Sometimes a poor contact between the valve seat insert and counterbore prevents the heat from being conducted away, and the result is high temperatures which deform the insert. When this occurs, both the seat and the valve will burn; in this case, the unit must be replaced.

Loose valve seats can be avoided only by proper installation. The counterbore must be thoroughly cleaned to remove all carbon before an insert is shrunk in. The valve seat is chilled with dry ice and the cylinder head is placed in boiling water for approximately thirty minutes; then the insert is driven into the counterbore with a large drift, as illustrated in figure 8–28. Never strike a

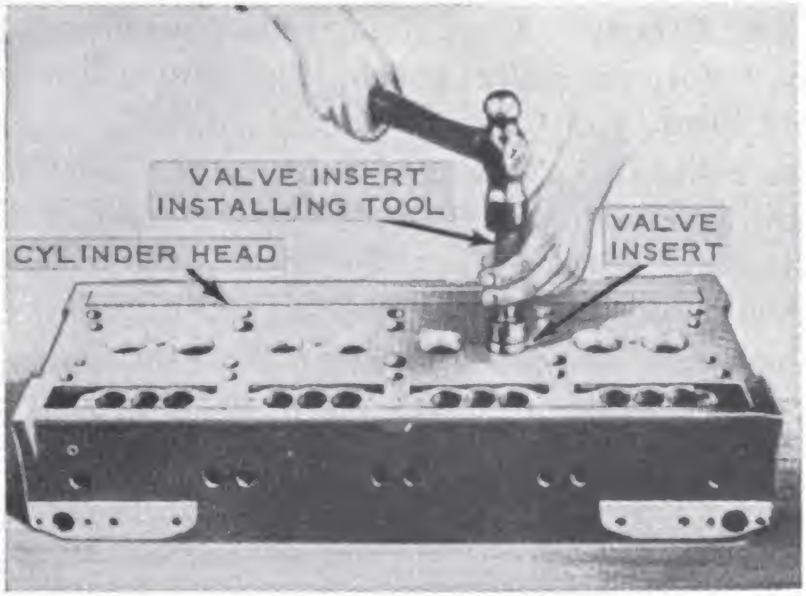


Figure 8–28.—Driving a valve insert into the cylinder head counterbore.

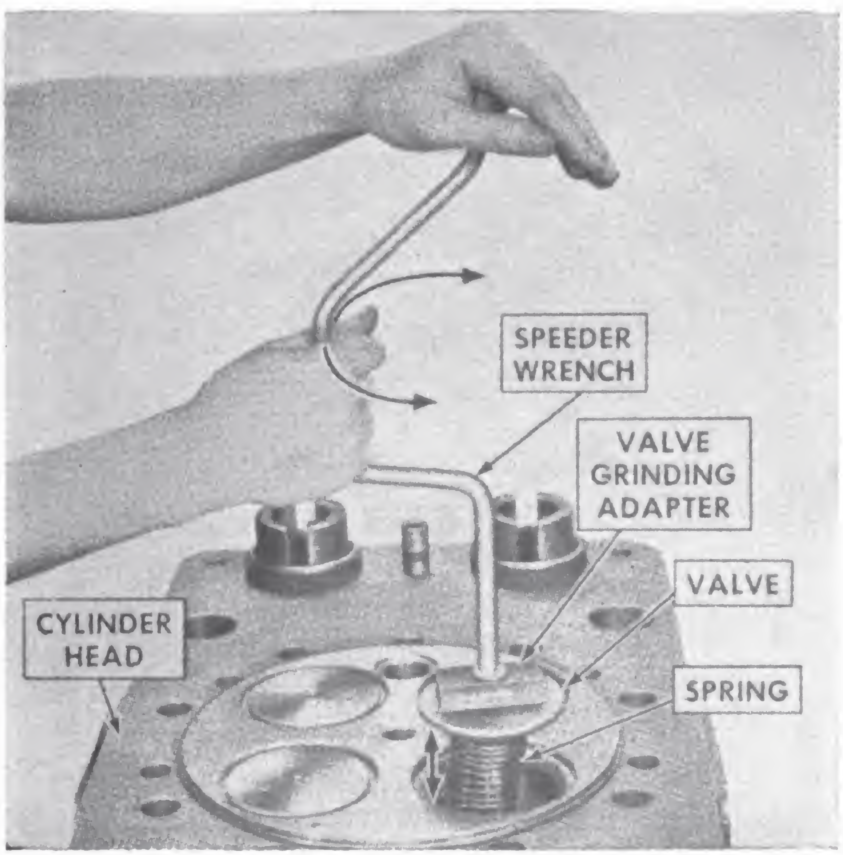


Figure 8–29.—Hand grinding a valve and valve seat.

valve seat directly. The driving operation must be done quickly, before the insert reaches the temperature of the cylinder head.

When replacing a damaged valve with a new one, inspect the valve guides (fig. 8–1) for excessive wear. If there is movement of the valve from side to side as it seats, the guides must be replaced.

If the valve seat is secured firmly in the counterbore and free of cracks and burns, slight damage such as pitting may be removed by hand grinding (fig. 8–29). The valve and valve seat are generally checked by using prussian blue, or, if this is not available, any thin dark oil

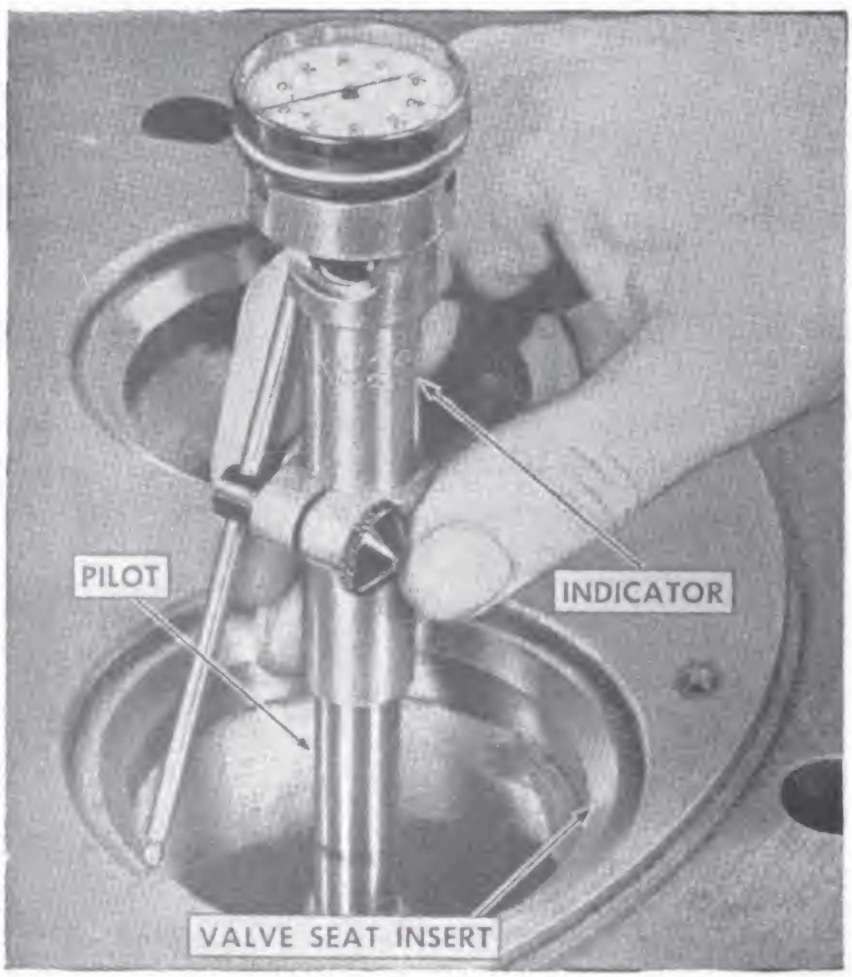


Figure 8–30.—Determining concentricity of the valve seat, with a dial indicator.

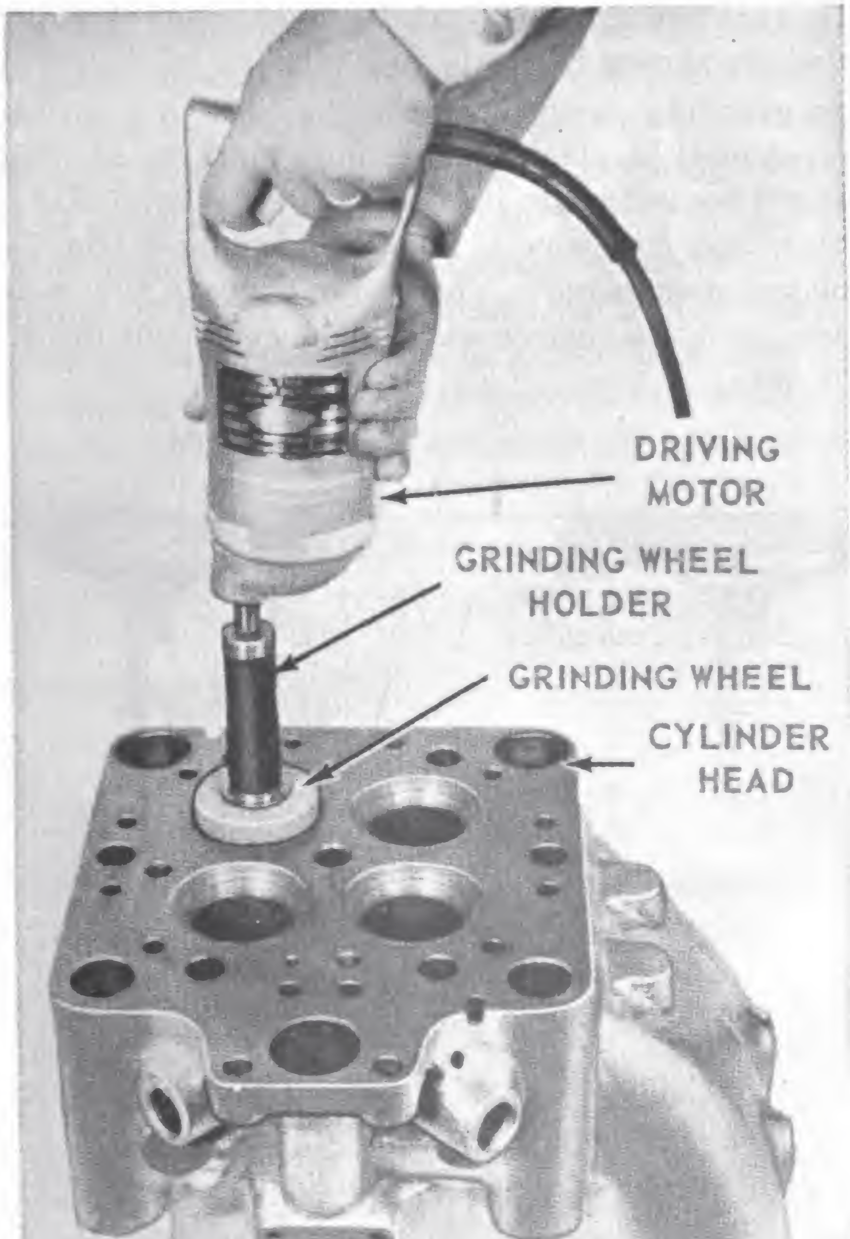


Figure 8–31.—Machine grinding a valve seat.

paint can be used. Allow the valve to seat from a short distance. If the surfaces fail to make complete contact, regrinding is necessary. In any valve reconditioning job, the valve seat must be concentric with the valve guide. This concentricity can be determined with a dial indicator, as shown in figure 8–30.

Hand-grinding methods should be held to a minimum and never used in place of machine grinding, in which a grinding stone is used to refinish the seat (fig. 8–31). In the latter case, the stone is placed on the pilot (fig. 8–30) and the motor engaged. The motor is run a few seconds at a time, and the seat checked after every cut until it is free of pits.

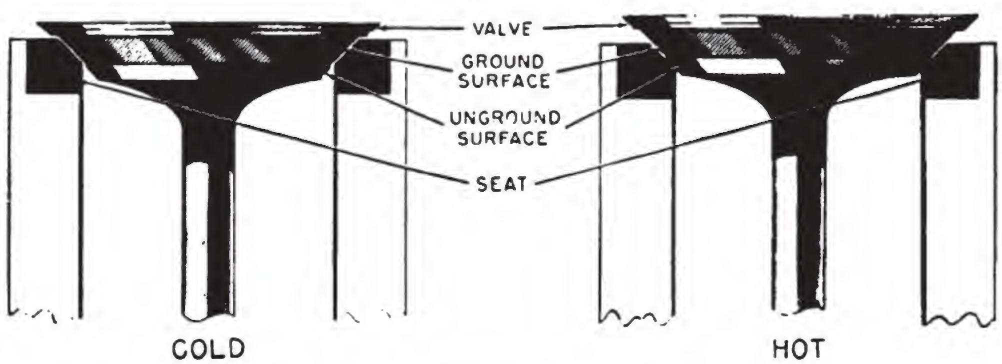


Figure 8–32.—Excessively hand-ground valves.

The objection to hand grinding the valve to the seat is that a groove or indentation may be formed in the valve face. Since the grinding is done with the valve cold, the position of the groove with respect to the seat is displaced when the engine is running, because of the excessive temperatures of the valve head over the valve seat. Such a condition is illustrated, and greatly exaggerated, in figure 8–32. Note that when "hot," the ground surface of the valve does not make any contact at all with the ground surface of the seat. Therefore, hand grinding should be used only to remove slight pit-

ting or as the final and finishing operation in a valve reconditioning job.

In some cases, valves and seats are not pitted sufficiently to require replacement, but are pitted to such an extent that hand grinding would be unsatisfactory. In such cases, the valves may be refaced on a lathe (fig. 8–33), and the valve seats reseated by power grinding equipment (fig. 8–31). Normally, these operations are done at a repair base or naval shipyard.

Valve heads which are excessively reground to such an extent that the edge is sharp, or almost sharp, will soon burn. A sharp edge is incapable of conducting the heat away at a rate sufficient to prevent burning. It is this factor that limits the extent to which a valve may be refaced.

BROKEN VALVE SPRINGS cause excessive valve noise, and may cause erratic exhaust gas temperatures. The actual breakage of the valve springs is not always the most serious consequence. When a spring breaks, it may

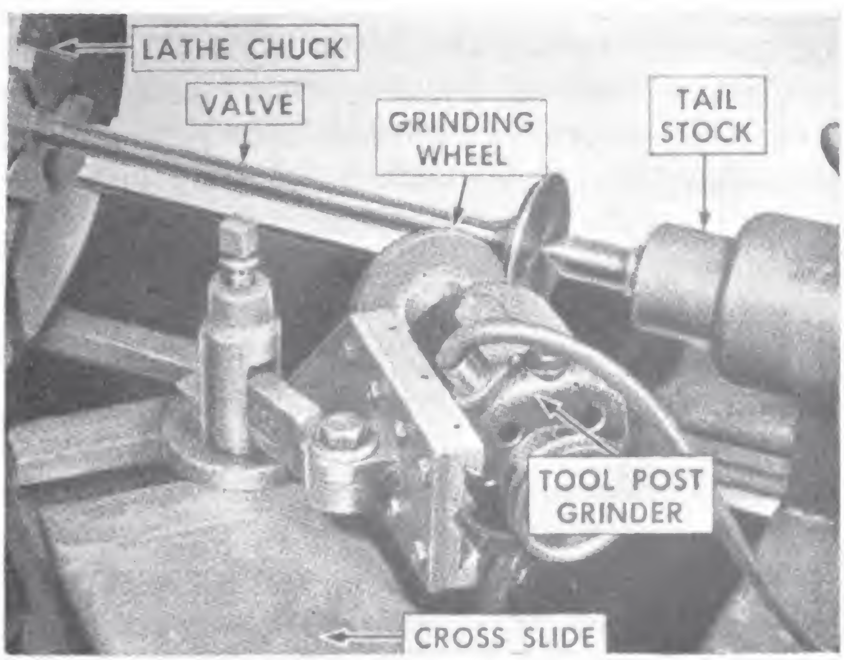


Figure 8–33.—Facing a valve on a lathe.

collapse sufficiently to allow the valve to drop into the cylinder; there it may be struck by the piston and extensive damage may result. In addition, the valve stem locks or keepers may drop into the cylinder, causing severe damage to the piston, cylinder head, and other adjacent parts.

A number of precautionary measures can be taken to prevent and minimize valve spring breakage and its causes (corrosion and metal fatigue). Reasonable care must be taken when assembling and disassembling. Before being reassembled, a valve spring must be thoroughly cleaned and inspected. (Kerosene or Diesel fuel should be used for cleaning—never an alkaline solution, for it will remove the protective coating.) The best indication of impending valve spring failure is the condition of the surfaces. (The use of magnaflux will greatly facilitate the finding of cracks which would otherwise be invisible.)

The free length of a spring should be within the limits specified in the instruction book. If such information is not available, compare the length of a new spring with that of the used spring. If the length of the used spring is more than 3 percent shorter than that of the new spring, the used spring should be replaced immediately. It must be remembered, however, that loss of spring tension will not always be reflected in a proportional loss of overall length. Springs which have not lost 3 percent of the proper value for their length may have lost sufficient tension to warrant replacement.

Springs with nicks, cracks, or surface corrosion must not be reinstalled in the engine. When the protective coating is nicked, a new coating should be applied. Corrosive conditions should be minimized and this can be best accomplished by using clean lube oil, eliminating water leaks, and keeping vents open and clean.

WORN VALVE KEEPERS and RETAINING WASHERS may result if valve stem caps (used in some engines) are improperly fitted. Such caps are provided to protect and

increase the service life of the valve stems. Trouble occurs when the cap does not bear directly on the end of the stem, bearing instead on the valve stem locks or spring retaining washer. This results in the actuating force being transmitted from the cap to the locks or retaining washer, and then to the stem, and thus causing excessive wear on the stem grooves and valve stem locks. As a result, the retaining washers will loosen and the valve stems may be broken.

An improper fit of a valve stem cap may result from the omission of spacer shims or the use of improper parts. Steel spacer shims, required in some caps to provide proper clearance, are placed between the ends of the valve stems and the caps; omission of the shims will result in the shoulder of the cap coming in contact with the locks. When disassembling a valve assembly, determine whether or not shims are used. If so, their location and exact thickness should be recorded. Valve caps must be of the proper size, or troubles similar to those resulting from shim omission will occur. Never attempt to use caps or any other valve assembly parts which are worn.

BROKEN VALVE HEADS usually cause an engine to come to an abrupt stop, the valve head being caught between the cylinder head and piston. If an engine continues to run after a valve head breaks loose, the resulting damage to the piston, liner, head, and other parts is generally repairable only by replacement of the parts.

Whether the causes of broken valve heads are mechanical deformation or metal fatigue, every precaution should be taken to prevent their occurrence. Since metal fatigue is relatively unpredictable, valves should be magnafluxed in order to locate cracks. If a valve head breaks loose, a thorough inspection must be made of all associated parts before making a replacement.

Ports

Two-stroke cycle engines invariably use cylinder ports for admitting air to the cylinders. These ports are lo-

cated sufficiently low in the cylinder so that the piston uncovers them as it approaches the bottom of its stroke.

The principal trouble encountered with ports is clogging which results from the formation of carbon deposits. Excessive deposits will form if the blower shaft seals allow oil leakage, or if the oil control rings are badly worn.

The formation of carbon about ports is as normal as the formations which accumulate in the cylinder. For efficient engine operation, the ports must be cleaned periodically. In most cases, access to ports is through inspection plates or hand-hole covers. On some installations, it is necessary to remove the intake air header. The cylinder heads must be removed in all cases to get all the carbon out of the cylinders. The cleaning of ports and the air box should be included with each carbon scraping operation. Doing this in addition to the regular periodic cleaning of air boxes will ensure that the ports are kept open and able to admit the full air charge in the proper manner.

Rocker Arms and Push Rods

The principal trouble encountered with rocker arms and push rods is WEAR which may occur in bushings, or on the pads, end fittings, or tappet adjusting screws.

The causes, prevention, and repair of worn rocker arm bushings are practically the same as for piston pin bushings. Any excessive wear of a bushing requires replacement of the part. Installation of a new bushing generally requires the use of a reamer for the final fit.

Wear at the points of contact on a rocker arm is generally in the form of pitted, deformed, or scored surfaces. Wear on the rocker arm pads and end fittings is greatly accelerated if lubrication is insufficient, or if there is excessive tappet clearance. Push rods are usually positioned to the cam followers and rocker arms by end fittings. The pads are the rocker arm ends that bear on the valve stem or valve stem cap. When the tappet

clearance is excessive, the rods shift around, greatly increasing the rate of wear of both the rocker arm and the rod contact surfaces. Worn fittings necessitate the replacement of parts. Continued use of a poor fitting and a worn push rod is likely to result in further damage to the engine, especially if the rod should come loose.

Worn tappet adjusting screws and lock nuts usually make it difficult to maintain proper clearances and to keep the lock nuts tight. Wear of the adjusting screws is usually caused by loose lock nuts, which allow the adjusting screw to work up and down on the threads each time the valve is opened and closed. This can be prevented by tightening down the lock nuts after each adjustment, and by checking the tightness at frequent intervals.

If the threads are worn, the entire rocker arm must be replaced. Attempts at repair, or the use of a new tappet adjusting screw, should be resorted to only in cases of emergency.

The adjustment of the rocker arm assembly consists chiefly of adjusting the tappets for proper running clearance. The valve clearance for both intake and exhaust valves should be readjusted after overhaul. The procedure for adjusting the rocker arm tappets of a typical engine (Cooper-Bessemer GSB–8) is as follows:

1. Observe the flywheel indicator, and rotate the engine to top dead center of the cylinder on which the tappets are to be adjusted.
2. Loosen the lock nut (jam nut) on the tappet screw, and insert a screwdriver in the slot of the screw.
3. Insert a feeler gage, of the proper thickness, between the tappet bearing and the end of the valve stem.
4. Tighten the tappet screw (fig. 8–34) until the feeler gage will just slide freely between the bearing and the valve.

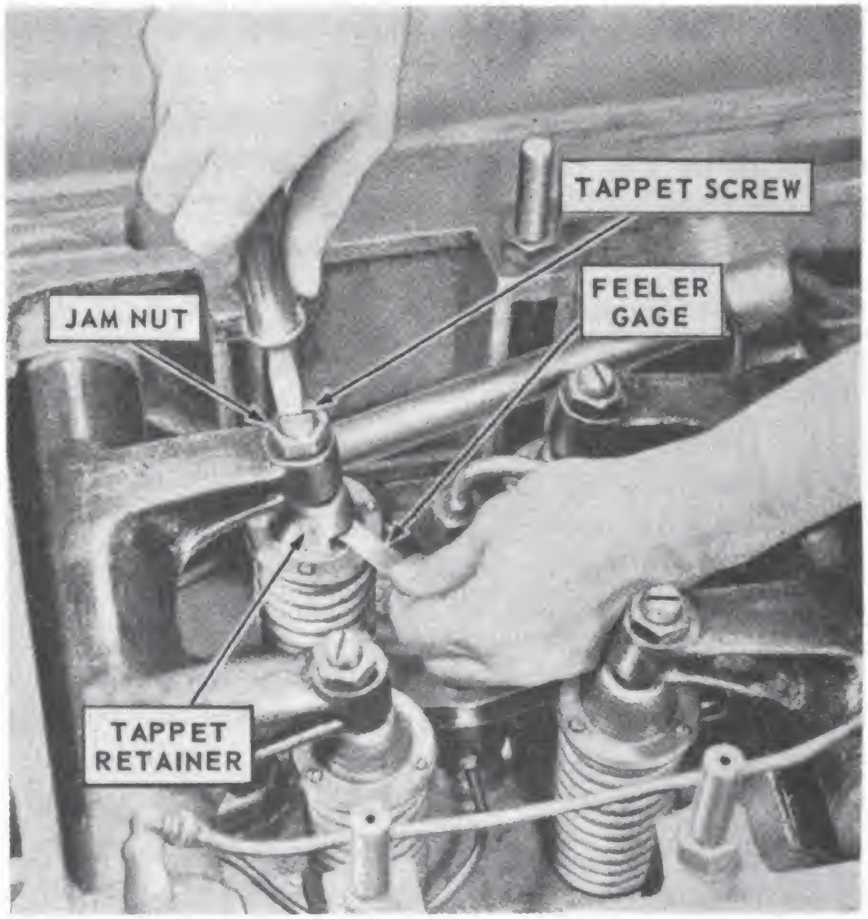


Figure 8–34.—Adjusting valve clearance.

5. Tighten the jam nut, and check the clearance. The jam nut has a tendency to increase the clearance when tightened; therefore, the clearance must always be checked after the jam nut is tightened.

The procedure outlined above is a preliminary, or "cold engine" check. Clearance should be checked and readjusted, if necessary, after the engine has been in operation for a short time and has reached the normal operating temperature.

Cam Followers and Lash Adjusters

Regardless of the type of cam follower, wear is the trouble most commonly experienced. Worn rollers usually are characterized by holes or pit marks in the roller surfaces; on the mushroom type, if the cam follower

fails to revolve, the cams usually wipe the same surface each time the camshaft revolves.

Normal use will cause surface disintegration, usually as a result of fatigue of the hardened surfaces. The condition is aggravated by abrasive particles. Nicks and dents on rollers will also start disintegration.

A constant check must be maintained for defective rollers or surfaces, and nicks, scratches, or dents in the camshaft. Whenever a defective cam follower is discovered, it should be replaced. In the case of roller type cam followers, a worn cam follower body and guide or roller needle bearings (if used) must be replaced.

Hydraulic valve lifters or lash adjusters function to provide a means of controlling valve gear clearances or lash. They may be installed on push rods, rocker arms, or on the cam follower. Figure 8–35 shows a larger sectional view of the hydraulic lash adjuster illustrated in figure 8–26.

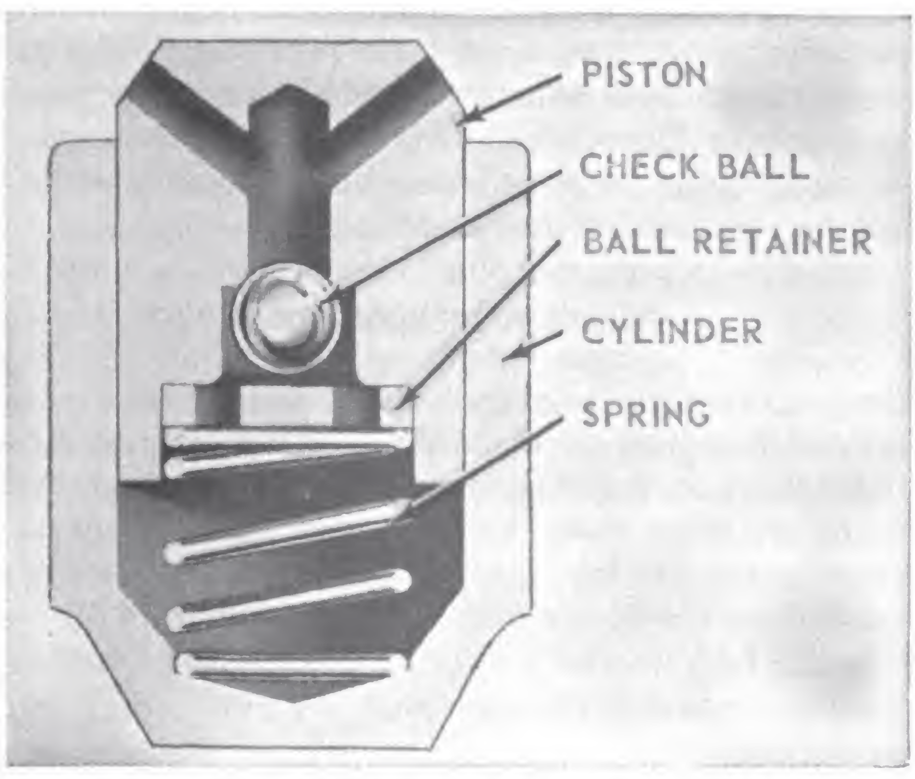


Figure 8–35.—Hydraulic lash adjuster.

Hydraulic lash adjusters may vary in design but generally consist of such basic parts as a cylinder, a piston or plunger, a ball check valve, and a spring. As precision parts, hydraulic valve lifters or adjusters require special care in handling and they must be kept exceptionally clean. Abrasive materials must be prevented from entering hydraulic lash adjusters, if they are to perform their function satisfactorily.

Defective or poorly operating valve adjusters allow clearance or lash in the valve gear. Noisy operation of a lash adjuster indicates that there is insufficient oil in the cylinder of the unit. Lack of oil may be due to one or more of the causes listed in figure 8–27. When a noisy lash adjuster is discovered and the oil supply or pressure is not the source of trouble, the unit should be removed from the engine and disassembled in accordance with manufacturer's instructions.

Since the parts are not interchangeable, only one unit should be disassembled at a time. Check for resinous deposits, abrasive particles, a stuck ball check valve, a scored check valve seat, and excessive leakage. All parts of the hydraulic lash adjuster should be carefully washed in kerosene or Diesel fuel. Such parts as the cam follower body, plunger or piston, and hydraulic cylinder should be checked for proper fit.

SHAFTS AND BEARINGS

The principal shafts (crankshafts and camshafts) and associated bearings (journal and antifriction bearings) of an internal combustion engine are all subject to several types of trouble. Some troubles may be common to all of these parts; others may be related to only one part. The causes of troubles which may be common to all parts are: metal fatigue, lubrication difficulties, and operation of the engine at critical speeds.

METAL FATIGUE, with respect to crankshafts, camshafts, and bearings, may result in shaft breakage or

bearing failure; however, fatigue is only one of several possible causes which may lead to such troubles.

Fatigue failure of journal bearings in internal combustion engines is usually caused by the cyclic peak loads encountered. Such failures are accelerated by improper or loose fit of the bearing shell in its housing, and lack of adequate priming of the lubricating oil system before starting the engine.

Severe overloading or overspeeding of an engine increases fatigue failure. Some indication of the cause of the failure may be obtained by noting which half of a bearing failed. Overloading of the engine will cause failure of the upper halves of main journal bearings, while overspeeding may cause the upper or lower halves to fail.

Crankshaft or camshaft failure seldom occurs. However, when such failure occurs, it may be due to metal fatigue. The causes of shaft fatigue failure are similar to those of journal bearing failure. Shaft fatigue failures generally develop over a long period of time. Such failures may be aggravated by improper manufacturing procedures, such as improper quenching or balancing, and by the presence of torsional vibration.

The importance of LUBRICATION cannot be overstressed. Much that has been stated previously about proper lubricants, and adequate supply and pressure of lube oils, as applied to valves, etc., is also applicable to crankshafts, camshafts, and the associated bearings. Some of the troubles which may be caused by improper lubrication are: damaged cams and camshaft bearing failure, scored or out-of-round crankshaft journals, and journal bearing failure. Lubrication difficulties that must be guarded against are: low lube oil pressure, high temperatures, and lube oil contamination by water, fuel, and foreign particles.

OPERATION OF AN ENGINE AT CRITICAL TORSIONAL SPEEDS, as well as in excess of the rated speed, will lead to engine shaft and bearing difficulties. Each multi-

cylinder engine has a critical speed, or several critical speeds, which must be avoided in order to prevent possible breakage of the camshaft, crankshaft, and gear train.

A critical speed of the first order exists when impulses due to combustion occur at the same rate as the natural rate of torsional vibration of the shaft. If the crankshaft receives an impulse from firing ~~at every other~~ natural vibration of the shaft, a critical speed of the second order occurs. Operation at these speeds for any length of time may cause the shaft to break. If critical speeds are not avoided, torsional vibrations may cause shaft breakage, as well as severe damage to the entire gear train assembly.

In some engines, critical speeds fall within the normal operating range. In such cases, the instruction manual for the specific engine will warn against engine operation for any length of time within the speed range. If the critical speed range falls within the normal operating range, it must be marked on the engine tachometer.

Overspeeding of an engine must be avoided. If the rated speed is exceeded for any extended period of time, the increase in inertia forces may result in excessive wear of the journal bearings and other engine parts, and in uneven wear of the journals.

Crankshafts

Broken or bent crankshafts may result from EXCESSIVE BEARING CLEARANCES. Excessive clearance in one main bearing may place practically all of the load on another main bearing. Flexing of the crankshaft under load may result in fatigue and fracture of the crank web, as shown in figure 8–36. Excessive bearing clearance may be caused by the same factors that cause journal bearing failures, mentioned later in the chapter. In addition, off-center and out-of-round journals tend to scrape off bearing material, which leads to excessive wear and an increase in the clearance between the shaft and the bearing. The possibility of journal out-of-roundness can be minimized by taking measures to prevent improper lu-

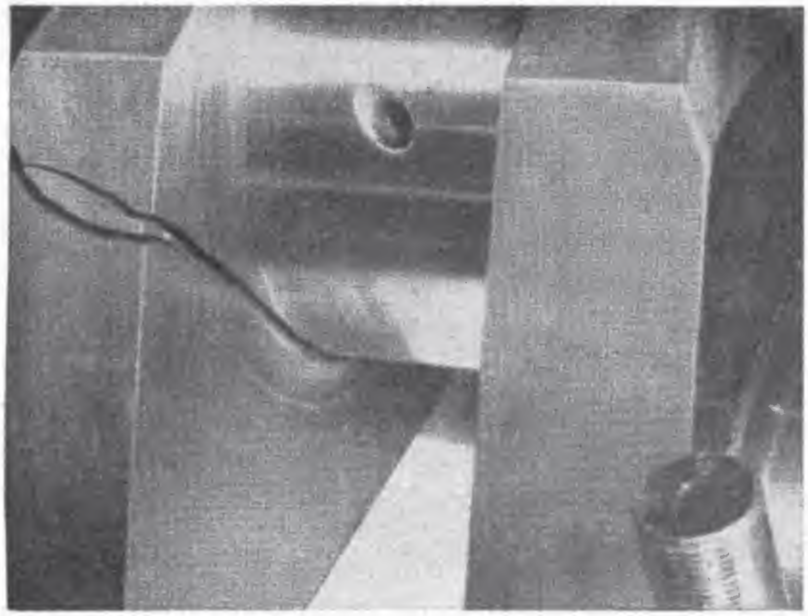


Figure 8–36.—Cracked crank web.

brication, journal bearing failure, overspeeding or overloading of the engine, excessive crankshaft deflection, and misalignment of parts.

Crankshaft bending, breakage, or out-of-roundness may result from EXCESSIVE CRANKSHAFT DEFLECTION. Excessive shaft deflection, caused by improper alignment between the driven unit and the engine, may result in a broken or bent shaft along with considerable other damage to bearings, connecting rods, and other parts. Overspeeding an engine may also cause excessive crankshaft deflection. The deflection of a crankshaft may be determined by the use of a strain gage (fig. 8–39).

Camshaft

In addition to the camshaft and bearing troubles and their causes already mentioned, the cams of a camshaft may be damaged as a result of improper valve tappet adjustment, worn cam followers, or the failure of camshaft gear.

Cams are likely to be damaged when a loose valve tappet adjustment or broken tappet screw causes the valve to jam against the cylinder head, and to jam the push

rods against their cams. This will result in scoring or breaking of the cams and followers, as well as severe damage to the piston and the cylinder.

Valves must be timed correctly at all times, not only for the proper operation of the engine but also to prevent possible damage to the engine parts. Frequent inspections of the valve actuating linkage should be made during operation to determine if it is operating properly. Such inspections should include taking tappet clearances and adjusting, if necessary; checking for broken, chipped, or improperly seated valve springs; inspecting push rod springs; inspecting push rod end fittings for proper seating; and inspecting cam follower surfaces for grooves or scoring.

Journal Bearings

In order to understand the causes for journal bearing failures, you should consider the loads which each bearing must withstand during operation. Depending upon the engine, the effect of loading on bearings varies. In the two-stroke cycle engine, the compressive and expansive forces are greater than the inertia forces set up by the reciprocating parts. This is due to the fact that for each cylinder a power stroke occurs with every revolution of the crankshaft. This causes a load to be placed always on the lower halves of the main bearings and of the piston pin bearings in the connecting rod, and upon the upper halves of the connecting rod bearings.

In the four-stroke cycle engine, large inertia forces are imposed during the intake and exhaust strokes. These forces tend to lift the crankshaft in its bearings. This results in a reversal of pressure, causing the load to be applied first on one half and then on the other half of the bearing. This also applies to double-acting engines, where there is a definite reversal of pressure in the bearings.

Engine journal bearing failures and their causes may vary to some extent, depending upon the type of bearing.

In general, the following discussion of the causes of bearing failure applies to most bearings—main bearings as well as crankpin bearings. The most common journal bearing failures may be due to one, or to a combination of the following causes:

CORROSION of bearing materials is caused by chemical action of the oxidized lubricating oils. Oxidation of oil can be minimized by changing oil at the designated intervals, and by maintaining engine temperatures within recommended limits. Bearing failures resulting from corrosion can generally be identified by the minute pits covering the surface, as shown in the magnified view, figure 8–37(A). A magnified view of a cross section of the same surface showing the type of pit (approximately 0.004 inch deep) formed as a result of corrosion is shown

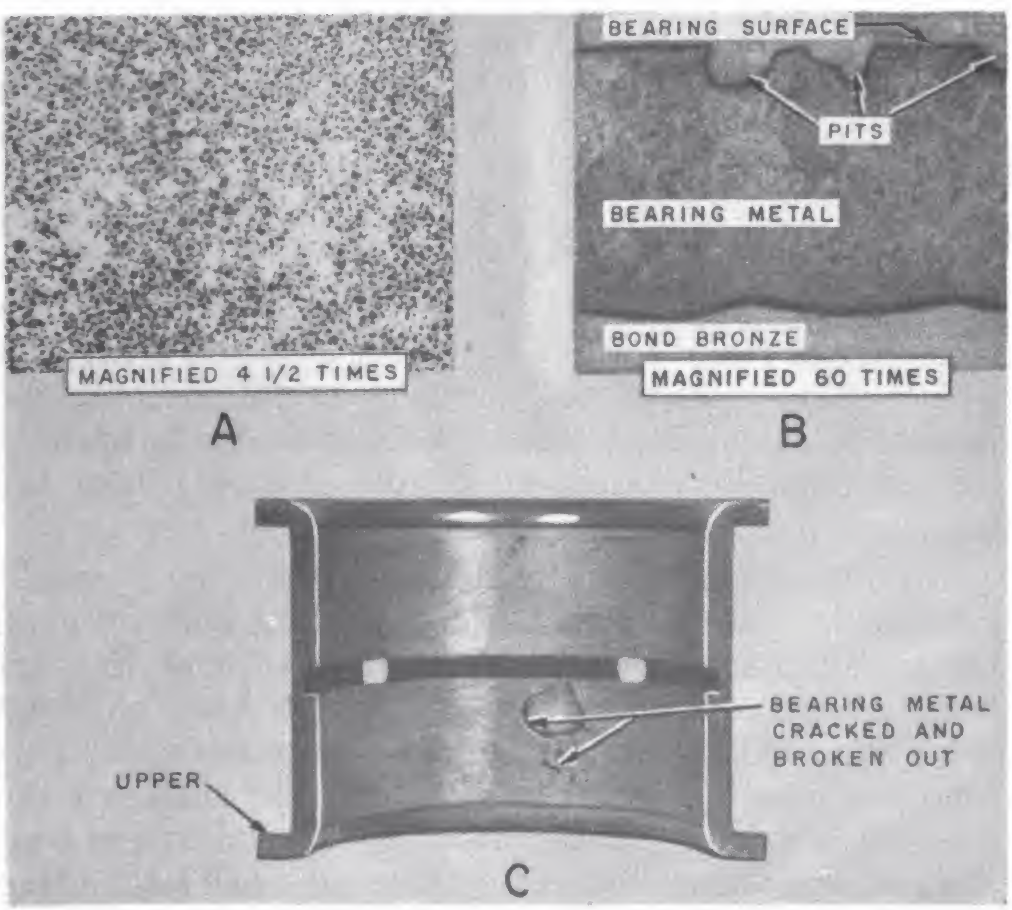


Figure 8–37.—Bearing failures due to corrosion and an inadequate bond.

in figure 8–37(B). In most cases, corrosion occurs over small bearing areas in which high localized pressures and temperatures exist.

INADEQUATE BOND between the bearing metal and the bearing shell may lead to journal bearing failure. A poor bond may be caused by fatigue resulting from cyclic loads, or it may be the result of defective manufacturing. A typical failure resulting from inadequate bond is shown in figure 8–37(C). In such failures, the bearing shell shows through the bearing surface clearly.

OUT-OF-ROUND JOURNALS, which cause journal bearing failures, result from excessive bearing wear. As the bearings wear, excessive clearance is created; this leads to engine pounding and will allow oil leakage from the bearing, possibly reducing the flow of oil to other bearings. Overheating, with consequent melting of bearing material, will result. To prevent bearing wear, the journals should be checked for out-of-roundness. Manufacturers require crank pins to be reground if the out-of-roundness exceeds a specified amount. The engine instruction manual should always be consulted to obtain this data.

During every overhaul, the journals should be inspected for rough spots—a burr or ridge may cause a groove in the bearing, and lead to bearing failure. If it becomes necessary to remove rough spots, use a fine oil stone and a piece of crocus cloth, and place a clean cloth beneath the journal to catch all particles. It is advisable to apply a coat of clean lubricating oil on the journal before the bearing is installed.

FAULTY INSTALLATION generally results from negligence or lack of experience. The most common failures, due to faulty installation, occur mainly through inattention to cleanliness as a result of which hard particles lodge between bearing shell and the connecting rod. This condition creates an air space between the shell and the connecting rod; this space retards the normal flow of heat and causes localized high temperatures. Such a condition may be further aggravated by the bearing surfaces being

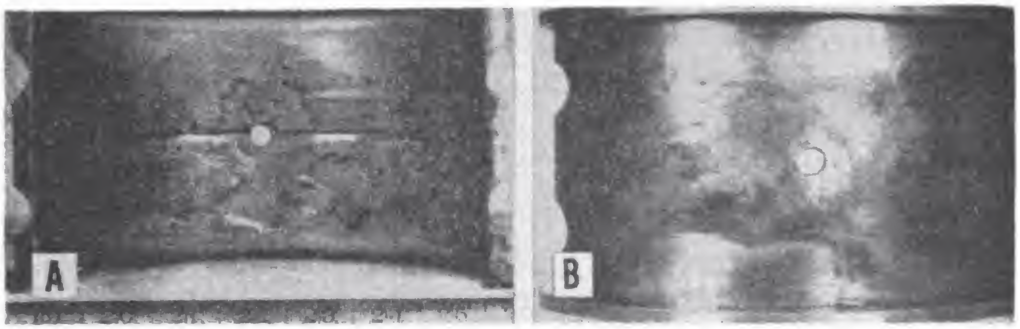


Figure 8–38.—Bearing failures caused by faulty installation.

forced out into the oil clearance space, creating a high spot in the bearing surface. The result may be a bearing failure caused by wiping and excessive temperatures, shown in figure 8–38(A). In addition, foreign particles, excessive clearance, or rough surface may cause poor contact between a bearing shell and a connecting rod. Poor contact is indicated by the formation of a gumlike deposit (sometimes referred to as lacquer or varnish) on the back of the shell, shown in figure 8–38(B).

Another source of trouble during installation is interchanging the upper and lower bearing shells. The installation of a plain upper shell in place of a lower shell, which carries an oil groove, completely stops the oil flow and leads to early bearing failures. The damage is not always limited to a ruined bearing, since it often extends to other parts, such as the connecting rod, piston, and wrist pin.

Maintenance and Repair of Shaft and Journal Bearings

The repair of crankshafts, camshafts, and bearings varies with the part as well as the extent of damage done. There is no doubt about the necessity for replacing such items as broken or bent crankshafts and camshafts, camshafts with damaged integral cams, and failed camshaft bearings. Out-of-round journals may be reground and undersize bearing shells installed, but this requires skilled personnel experienced in the use of precision tools. If available, a new shaft should be installed and the damaged shaft sent to a salvage reclamation center. Under certain conditions, scored crankshaft journals or dam-

aged journal bearings may be kept in service if proper maintenance is performed.

Repair of SCORED JOURNALS depends upon the extent of scoring. If a crankshaft has been overheated, the effect of the original heat treatment will have been destroyed and it will be advisable to replace the crankshaft.

If journal scoring is only slight, an oil stone can be used for dressing purposes, provided that precautionary measures with respect to abrasives are observed during the procedure. During the dressing operation, it is advisable to plug all oil passages within the journal, and those connecting the main bearing journal and the adjacent crank pin.

In the dressing procedure, a fine oil stone, followed with crocus cloth, should be used to polish the surface. After dressing, the journals must always be washed with Diesel oil. This procedure must include washing of the internal oil passages as well as the outside journal surfaces. Some passages are large enough to accommodate a cleaning brush, and smaller passages can be cleaned by blowing out with compressed air. The passages should always be dried by blowing with compressed air.

NEVER STOW A CRANKSHAFT OR BEARING PART ON ANY METAL SURFACE. When a shaft is removed from an engine, it should be placed on a wooden plank with all journal surfaces protected. If the shaft is to be exposed for some time, it is well to protect each journal surface with a coating of heavy grease. Bearings should always be placed on wooden boards or clean cloths.

CRANKSHAFT overhaul consists not only of an inspection and servicing for scoring and wear, but also a determination of each crank web deflection. Some manufacturers recommend that deflection readings be taken, during every periodic overhaul, at each crank.

A strain gage, often called a crank web deflection indicator, is used to take deflection readings. This gage is merely a dial-reading inside micrometer used to measure the variation in the distance between adjacent crank webs

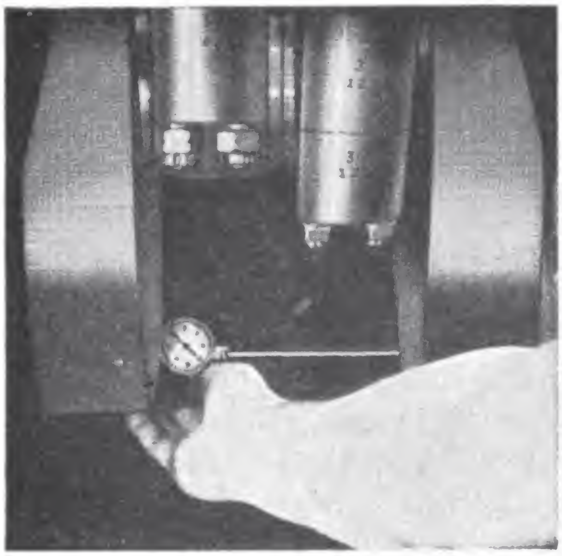


Figure 8–39.—Strain gage between crank webs.

as the engine shaft is barred over. Figure 8–39 shows a strain gage between crank webs.

When installing the gage, or indicator, between the webs of a crank throw, see that the gage is placed as far as possible from the axis of the crank pin. The ends of the indicator should rest in prick-punch marks in the crank webs. If these marks are not present, they must be made so that the indicator may be placed in its correct position. Consult the engine instruction manual for the proper location of new marks.

Readings are generally taken at the four crank positions: top dead center, inboard, near or at bottom dead center, and outboard. In some engines, it is possible to take readings at bottom dead center. In others, the connecting rod may interfere, making it necessary to take the reading as near bottom dead center as possible, without having the gage come in contact with the connecting rod. The instruction manual for the specific engine contains information concerning the proper position of the crank when readings are to be taken. When the gage is in its lowest position, the dial will be upside down, necessitating the use of a mirror and flashlight so that a reading can be obtained.

Once the indicator has been placed in position for the first deflection reading, the gage should NOT be touched until all four readings have been taken and recorded.

Variations in the readings obtained at the four crank positions will indicate distortion of the crank. This distortion may be caused by several factors, such as a bent crankshaft, worn bearings, or improper engine alignment. The maximum allowable deflection can be obtained from the engine instruction manual. If the deflection exceeds the specified limit, steps must be taken to determine the cause of the distortion and correct the trouble.

Deflection readings are also employed in determining correct alignment between the engine and the generator, or between the engine and the coupling. However, when alignment is being determined, a set of deflection readings is usually taken at the crank nearest the generator or the coupling. In aligning an engine and generator, the installation of new chocks between the generator and its base may be necessary to bring the deflection with the allowable value. It may also be necessary to shift the generator horizontally to obtain proper alignment. When an engine and a coupling are to be aligned, the coupling must first be correctly aligned with the drive shaft then the engine properly aligned to the coupling, rather than the coupling to the engine.

CAMSHAFTS can be saved when the cams alone are damaged, if the cams are of the individual type, since such cams may be removed and replaced. Figure 8–40 illustrates the method of removing an individual cam from its shaft.

When a camshaft is removed from the engine, it must be thoroughly cleaned. (Kerosene or Diesel fuel may be used.) After the shaft is cleaned, it should be dried with compressed air. After the cam and journal surfaces are cleaned, they should be inspected for any signs of scoring, pitting, or other damage.

When a camshaft is being inserted or removed by way of the end of the camshaft recess, the shaft should be

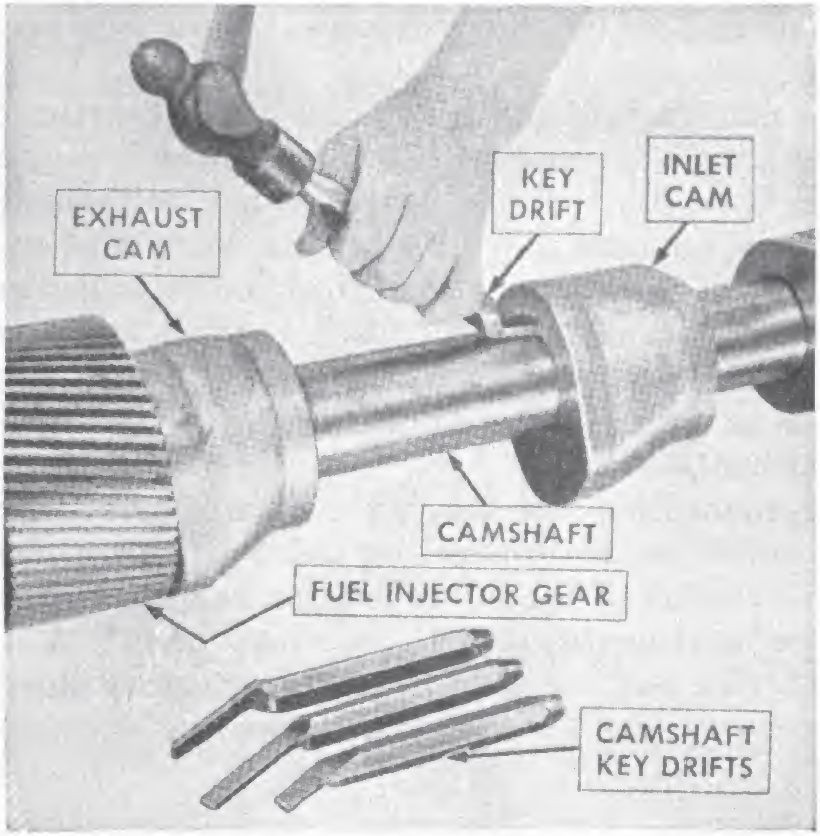


Figure 8–40.—Removing an individual cam.

rotated slightly. This allows the camshaft to enter easily, and reduces the possibility of damage to the cam lobes and the bearings.

JOURNAL BEARINGS may perform satisfactorily with as much as 10 percent of the load-carrying area removed by fatigue failure. Other minor casualties may be repaired so that a bearing will give additional hours of satisfactory service.

Bearings should not be rejected or discarded for minor pits, heavy scratches, or areas indicating metallic contact between the bearing surface and the journal. Minute pits and raised surfaces may be smoothed by using crocus cloth or a bearing scraping tool. After work has been performed on bearings, every effort must be made to ensure the cleanliness of the bearing surfaces. This also applies to the bearing back and the crank journal and pin. A thin film of clean lubricating oil should be placed on the

journals and the bearing surfaces, before they are reinstalled.

The markings of the lower and upper bearing halves should always be checked in order that they may be installed correctly. Many bearings are interchangeable when new, but once they have become worn to fit a particular journal or crank pin, they must be reinstalled on that particular journal or pin. Each bearing half must be marked or stamped with its location (cylinder number) and the bearing position (upper or lower) to prevent incorrect installation.

The connecting rod bearing cap nuts must be pulled down evenly on the connecting rod bolts to prevent possible distortion of the lower bearing cap and consequent damage to bearing shells, cap, and bolts. A torque wrench (fig. 8–41) should be used to measure the torque

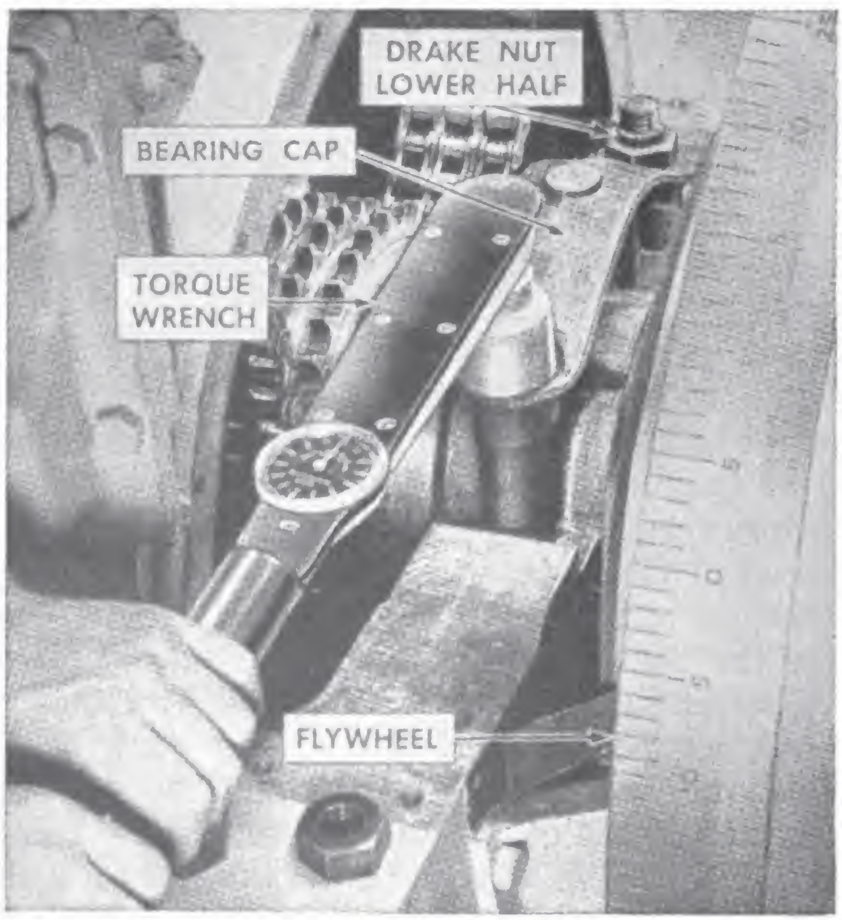


Figure 8–41.—Using a torque wrench to tighten a main bearing.

applied to each bolt and nut assembly. The same torque must be applied to each bolt. If a manufacturer recommends the use of a torque wrench, the specified torque may be obtained from the instruction manual.

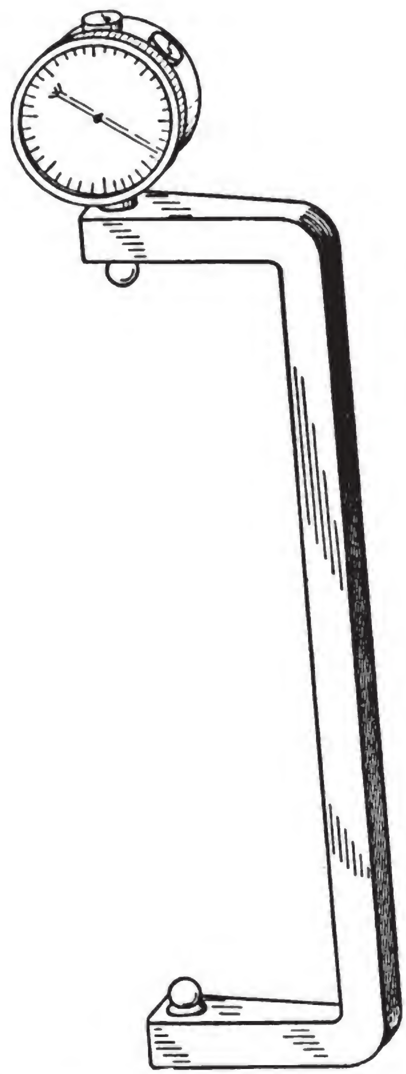


Figure 8–42.—Gage used for measuring bolt elongation.

Another method used to pull down the nuts evenly is to stretch each bolt an equal amount, the stretch being measured from end to end of the bolt before and after tightening. Figure 8–42 shows the type of gage used, and figure 4–43 illustrates the gage installed on the engine. The proper elongation may be obtained from the engine instruction manual.

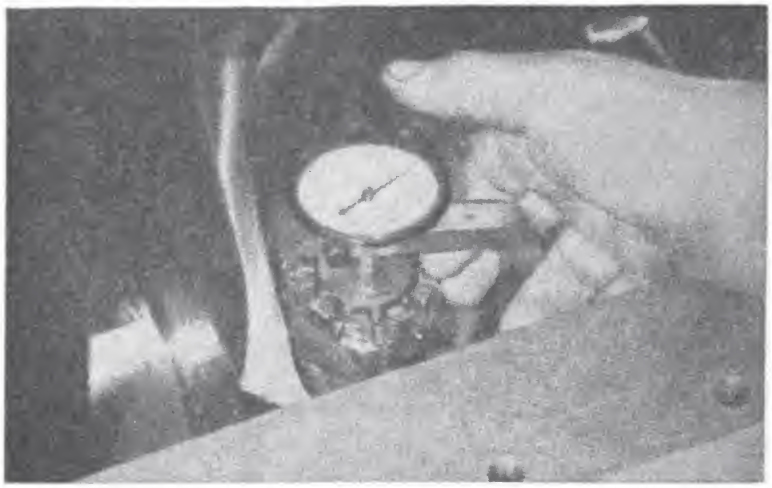


Figure 8–43.—Measuring bolt elongation.

After a bearing is reassembled, the engine should always be barred or jacked over by hand through several revolutions, to ensure that all reciprocating and rotating parts are functioning freely and that no binding exists between the main and connecting rod bearings and the crankshaft. The larger Diesel engines must be turned over, first by manual jacking gear provided, and then by the engine starting system.

The use of leads, shim stock, or other such devices is not recommended for determining the clearances of precision bearings. If they are used, there is danger that the soft bearing material may be seriously damaged. A micrometer especially fitted with a spherical seat should be used to obtain the thickness of bearing shells. The spherical tip must be placed against the inside of the bearing shell to obtain an accurate reading and to prevent injury to the bearing material. Figure 8–44 shows a micrometer caliper especially fitted with a steel ball for measuring bearing thickness.

Measurements must be taken at specified intervals, usually at every overhaul, to establish the amount of bearing wear. In addition, a sufficient number of crankshaft journal diameter measurements should be taken at suitable points, to determine possible out-of-roundness.

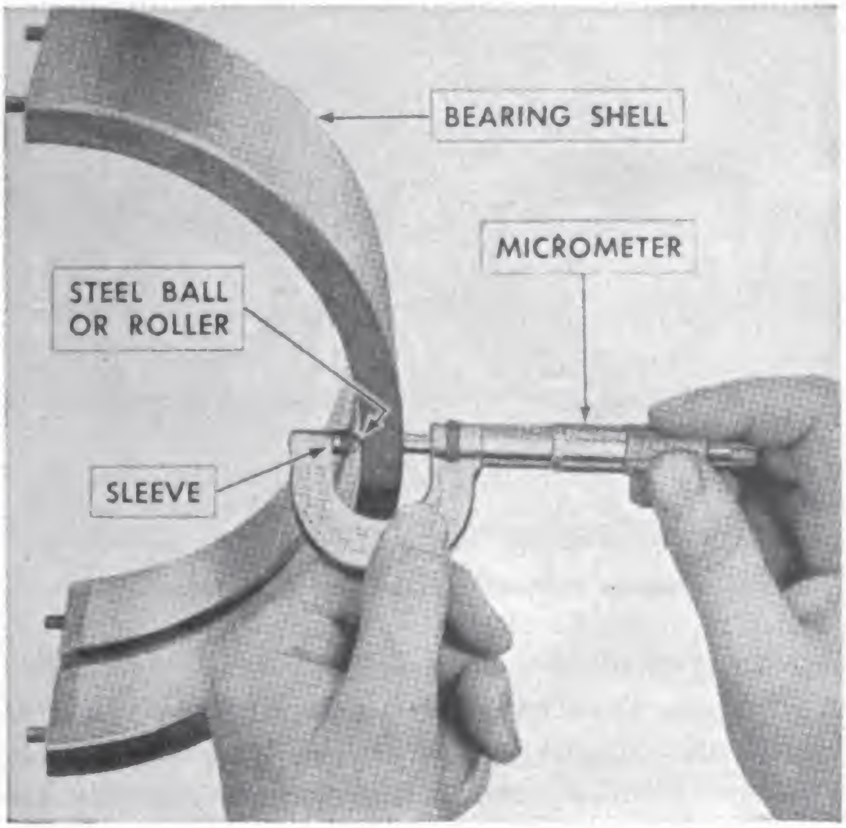


Figure 8–44.—Measuring bearing shell thickness.

With some types of engines, a crankshaft bridge gage (fig. 8–45) is provided to check the wear of the main bearing shells. The gage is placed on the crankshaft, as shown, and the clearance between the bridge gage and shaft is measured by feeler gages. Any variation between this clearance and the correct clearance (usually stamped on the housing of each bearing) indicates that main bearing wear has occurred. The maximum limits of wear are given in the manufacturer's instruction book. Some engine manufacturers require that, at every overhaul, bridge gage readings be taken in conjunction with crank web deflection measurements.

SUMMARY

You should be familiar with the common engine casualties, their symptoms and causes as well as the preventive measures which may be taken to minimize future failures.

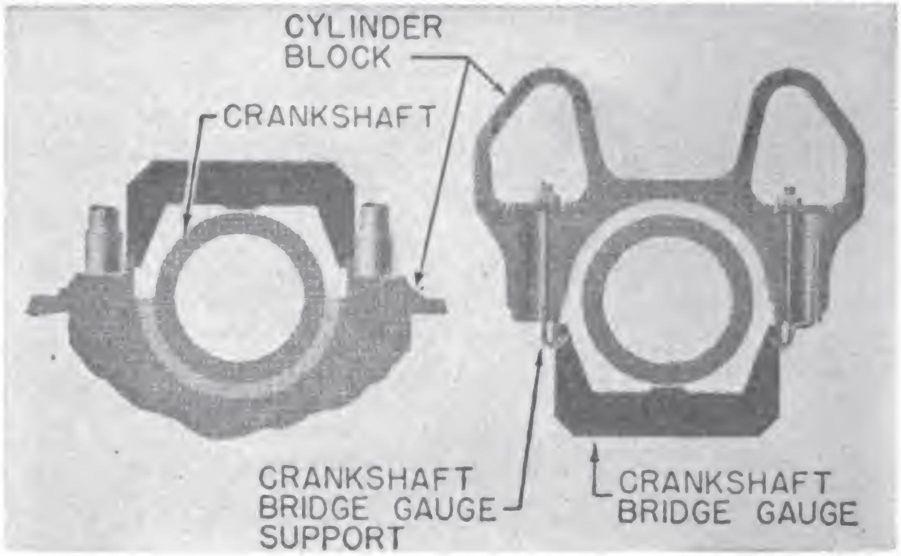


Figure 8–45.—Crankshaft bridge gage.

In addition, you should have a general understanding of the procedures involved and the precautions necessary in the care and maintenance of the various engine parts; particularly cylinder, and piston and connecting rod assemblies.

With respect to engine valves, intake and exhaust valves should be carefully inspected for cracks, pitting, distortion, burning, and any other defect which may affect engine efficiency. In most cases replacement is necessary when such troubles occur. When a valve is being secured in a cylinder head, see that all parts are properly assembled with the correct clearances.

Bearings and shafting should be given particular attention. Journal bearings should be checked to ensure that excessive scoring or out-of-roundness does not exist. Since misalignment may result in crankshaft or main bearing failure, gage readings and crank web deflections should be checked during engine overhaul.

QUIZ

1. How may foreign material between the contact, or mating, surfaces of a dry liner result in a liner crack?
2. What is the best method for detecting scoring in a cylinder liner?
3. How may badly worn pistons and rings cause scoring of a liner?
4. If excessive liner wear exists beyond the specified limits, what should be done?
5. How many excessive carbon deposits in the combustion space affect engine operation?
6. When stud nuts are to be tightened, what precaution should be taken to prevent unnecessary wear and distortion, and inaccurate torque readings?
7. What two symptoms may be indicative of excessive clearance between a piston and cylinder liner?
8. With respect to the design of most pistons now in use, what has been done to reduce piston crown and ring dragging?
9. With respect to lubrication, how may improper cooling water temperatures cause piston casualties?
10. What may appear as a false indication of piston crown dragging when a piston is being inspected for signs of dragging?
11. For correct piston ring operation, why must proper clearance be maintained between the ring and the land, and also between the ends of the ring?
12. When worn oil rings are suspected as the cause of excessive oil consumption, what other possible causes should be checked before replacing the rings?
13. If a piston ring breaks, what symptom indicates that breakage resulted from an insufficient gap clearance?
14. What check is made to determine the sealing qualities of a piston ring?
15. With respect to cylinder liners, what factors must be considered when new piston rings are installed?
16. What should generally be done to a cylinder liner before a piston assembly is removed?
17. When a piston ring is stuck securely in a groove, what two methods can be used, if necessary, to free the ring?
18. What precaution must be taken when measuring piston pins and bushings for wear?

19. What indications usually signify that a piston pin and bearing are damaged because of a misaligned connecting rod?
20. If a new piston pin bushing has been installed and the clearance is inadequate, what step must be taken?
21. When a resinous deposit is being removed from around a stuck valve stem, why must care be taken to prevent the entrance of any appreciable amount of fluid into the cylinder?
22. What is the principal cause of burned exhaust valves?
23. How may a poor contact between a valve seat insert and its counterbore lead to the burning of a valve head?
24. What is the principal objection to reconditioning a valve and valve seat by the hand-grinding method?
25. What factor limits the extent to which a valve head may be refaced?
26. What are the two chief causes of valve spring breakage?
27. What is the principal trouble encountered with cylinder ports?
28. What is the principal trouble encountered with cam followers, and rocker arm and push rod assemblies?
29. What is indicated by the noisy operation of a hydraulic lash adjuster?
30. When hydraulic lash adjusters are being disassembled, what precaution should be taken?
31. If overloading of the engine is the cause of a main journal bearing failure, which half of the bearing is most likely to fail?
32. If a crankshaft breaks when the engine is operating within the critical speed range, what is the probable cause of failure?
33. What steps should be taken to avoid crankshaft breakage which is caused by excessive shaft deflection?
34. In general, how can bearing failures resulting from corrosion be identified?
35. What should be used to remove rough spots or light scoring from the journals of a crankshaft?
36. When a strain gage is installed to measure crank web deflection, where should it be located with respect to the crank pin?
37. When crank web deflection is being measured, readings should be taken at what crank positions?
38. If a torque wrench is not available, what other approved method may be used to ensure that connecting rod bolts are tightened down evenly?

CHAPTER 9

TESTING OF FUEL AND LUBRICATING OILS

Petroleum products are stowed and handled aboard ship in accordance with BuShips recommendations and instructions. As a Fireman, you learned about the stowage, service, and contamination tanks of the fuel oil system. As an Engineman 3, you were responsible for knowing the path of lubricating oil in both Diesel and gasoline engines. As an Engineman 2, you must be familiar with the testing procedures for quality characteristics of oils.

When Diesel oil is received aboard ship, it is generally satisfactory with respect to Navy requirements. However, it should be checked regularly for cleanliness and for possible contamination by water and sediment, since poor quality fuel will lead to inefficient engine performance. Proper lubrication of shipboard equipment also requires that the lube oil meet the prescribed standards.

CHARACTERISTICS AND TESTS

Lubricants obtained by the Navy are tested for such characteristics as viscosity, pour point, flash point, fire point, autogenous-ignition point, neutralization number, demulsibility, and precipitation number. The lubricants must meet the following requirements:

1. They must have a suitable viscosity at the operating temperature of the bearing being lubricated.

2. They must form durable boundary films on the metal rubbing surfaces.
3. They must not chemically attack the journal, or the bearing metals.
4. They must not change chemical composition with use.

Viscosity

The tendency of a liquid to resist flow or change of shape is known as viscosity. A liquid of high viscosity flows very slowly. The viscosity of any oil will vary with an increase or a decrease in temperature. The viscosity decreases when the temperature is increased, and it increases when the temperature is decreased. (On a cold morning, it is difficult to turn over an engine because of the high viscosity, or stiffness, of the lube oil.)

Viscosity at operating temperatures should be high enough for the oil to maintain a fluid film regardless of the load imposed upon it. However, the viscosity should not be so high that it causes drag or excessive fluid friction, which, in turn, reduces engine efficiency and results in high bearing temperatures. The viscosity at operating temperatures determines the fluid friction, the heat generated in the bearing, and the rate of flow of the oil under given conditions. Therefore, viscosity of oils at operating temperatures must be known in order to select the proper oil for a specific purpose.

DETERMINING THE VISCOSITY.—The measure of the viscosity of an oil is the number of seconds required for a specified quantity (60 cc), at a specified temperature, to flow through a standard orifice. When the viscosity of an oil is measured, the result is reported in a 3-unit term containing (1) the number of seconds required for the sample of oil to pass through the orifice, (2) the type of viscosimeter used (this indicates the orifice size), and (3) the temperature of the oil tested. Navy fuel oil is generally tested in a Saybolt Furol Viscosimeter (illustrated

in figure 9–1), and lubricating oil is generally tested in a Saybolt Universal Viscosimeter. Thus, the viscosity of a fuel oil might be expressed as 20 seconds Saybolt Furol at 122° F (standard temperature used for testing fuel oil), and the viscosity of a lubricating oil might be expressed as 190 seconds Saybolt Universal at 130° F. For testing a lubricating oil, 100° F and 210° F are also used as standard temperatures, depending upon the symbol of the individual oil.

The only difference between the Saybolt Furol Viscosimeter and the Saybolt Universal Viscometer is in the size of the discharge orifice, about one-tenth the time is required for a specific quantity of oil, at a given viscosity, to flow through the orifice of a Saybolt Furol instrument as through the orifice of a Saybolt Universal Viscosimeter.

Since temperature is an important factor in determin-

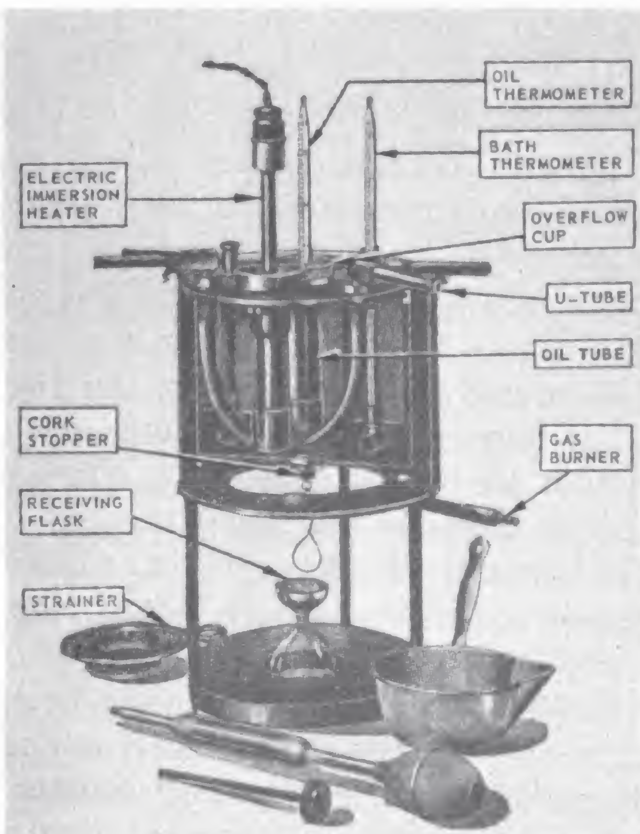


Figure 9–1.—Saybolt Furol Viscosimeter.

ing viscosity, it is necessary to watch the thermometer readings carefully. With the Saybolt Furol Viscometer, two thermometers are provided, one to record the temperature of the outer bath vessel, and the other to check the temperature of the oil being tested.

To test the viscosity of a sample of fuel oil, proceed as follows:

1. Fill the bath vessel with a light engine oil and raise the temperature of the unit, with the electric heating coil. If electricity is not available, heat the vessel either with a burner or by running steam through the U-tube. If it becomes necessary to cool the oil, pass cold water through the U-tube.
2. Fill the oil tube to its upper edge with the oil to be tested. When the temperatures of the oil in the oil tube and the bath are equal (122° F), adjust the heat to maintain that temperature. Remove the thermometer from the tube, and leave the one in the bath vessel. (See that the bath temperature is maintained, throughout the test, at 122° F.)
3. Then pull the cork and start a stop watch. The time in seconds indicated on the watch is the viscosity of the oil at that temperature; for example, 20 Seconds Saybolt Furol (20 SSF) at 122° F.

As an Engineman 2, you should be familiar with the recommended procedure for checking the viscosity of a LUBE OIL. The importance of using lube oil of the correct viscosity cannot be overemphasized. When making an oil change, it is easy to see that the right oil is used. However, the viscosity of the lube oil in an engine changes while the engine is running; the change is usually toward a lower viscosity because of dilution with fuel oil.

A simple device for checking viscosity is the VISGAGE, shown in figure 9–2. (The gage is filled and sealed at the factory; the Engineman should NOT tamper with this instrument.) The visgage consists of two glass tubes attached to a scale calibrated in Seconds Saybolt Universal

(SSU) at 100° F. The MASTER TUBE (upper tube) contains a small steel ball immersed in oil which has a viscosity of 200 SSU at 100° F (standard for the testing of other oils).

Figure 9–2.—The visgage.

The TRIAL TUBE is similar to the master tube, but has a plunger by means of which a sample of any oil to be tested can be drawn into the tube. The steel ball in the trial tube is identical with the one in the master tube.

Before studying the operation of the visgage, notice the two scales between the tubes. Both scales are used to read the viscosities of sample oils drawn into the trial tube. Scale *A*, adjacent to the master tube, is calibrated from 200 at the left to 0 at the right, and scale *B*, adjacent to the trial tube, from 200 at the left to 2000 at the right.

When using the visgage, put a small sample of oil in a clean container. Insert the nozzle of the trial tube into the oil, and draw the plunger all the way up, filling the trial tube with the oil. Then tilt the left end of the instrument down at about a 30° angle, so that steel balls roll down through the oils. Be careful to keep the sample oil from coming out of the nozzle.

If the viscosities of the samples and the standard oils differ, the two steel balls will move downward at different speeds in the tubes. As the leading one approaches the 200 line at the left end of the scale, gradually tilt the left end of the visgage upward. This action will slow up the movement of the steel balls.

At the instant the leading ball reaches the 200 line, bring the visgage back to level and, at the same time, read the position of the lagging, or slower-moving, ball on the

nearest scale. That reading will be the viscosity of the sample oil, in SSU at 100° F.

If the ball in the upper tube travels faster, read the position, on scale *B,* of the ball in the trial tube at the moment the upper ball reaches the 200 line. That reading will be the viscosity of the sample oil at 100° F (for example, 275 SSU).

If the lower ball (in the sample oil) is the one that travels faster, read the position, on scale *A,* of the ball in the master tube, at the moment the lower ball reaches the 200 line. That reading—for example, 125 SSU—is the viscosity of the sample oil at 100° F.

However, if the two balls move at the same speed and reach the left end of the visgage together, the viscosity of the sample oil is the same as that of the standard oil.

Remember that the temperature of both the sample oil and the standard oil should be approximately 100° F. By holding the gage for a few minutes in the palms of your hands, you can adjust the temperature of the oils. This will warm the oils to body temperature (98.6° F), which is approximately 100° F.

Determining the viscosity of the sample lube oil doesn't solve the problem. What you want to know is whether the oil has become diluted to such an extent that it should no longer be used. Having finished using the visgage to determine the viscosities of both the new and the old oils, you should then turn to a dilution chart (figure 9–3). Such a chart illustrates how the percentage of dilution of the lubricating oil, by the fuel oil, can be determined.

Assume that the viscosity of the new oil (*A* in fig. 9–3) is 550 seconds and that of the old oil (*B* in fig. 9–3) is 480 seconds. Values A and B are found on the chart and the respective horizontal and vertical lines drawn to the point of intersection, C. The latter point falls on the 2 percent line, which indicates the amount of dilution of the used lube oil with the fuel oil.

A lube oil should be changed when it has a 5 percent dilution. Under certain conditions the oil should be

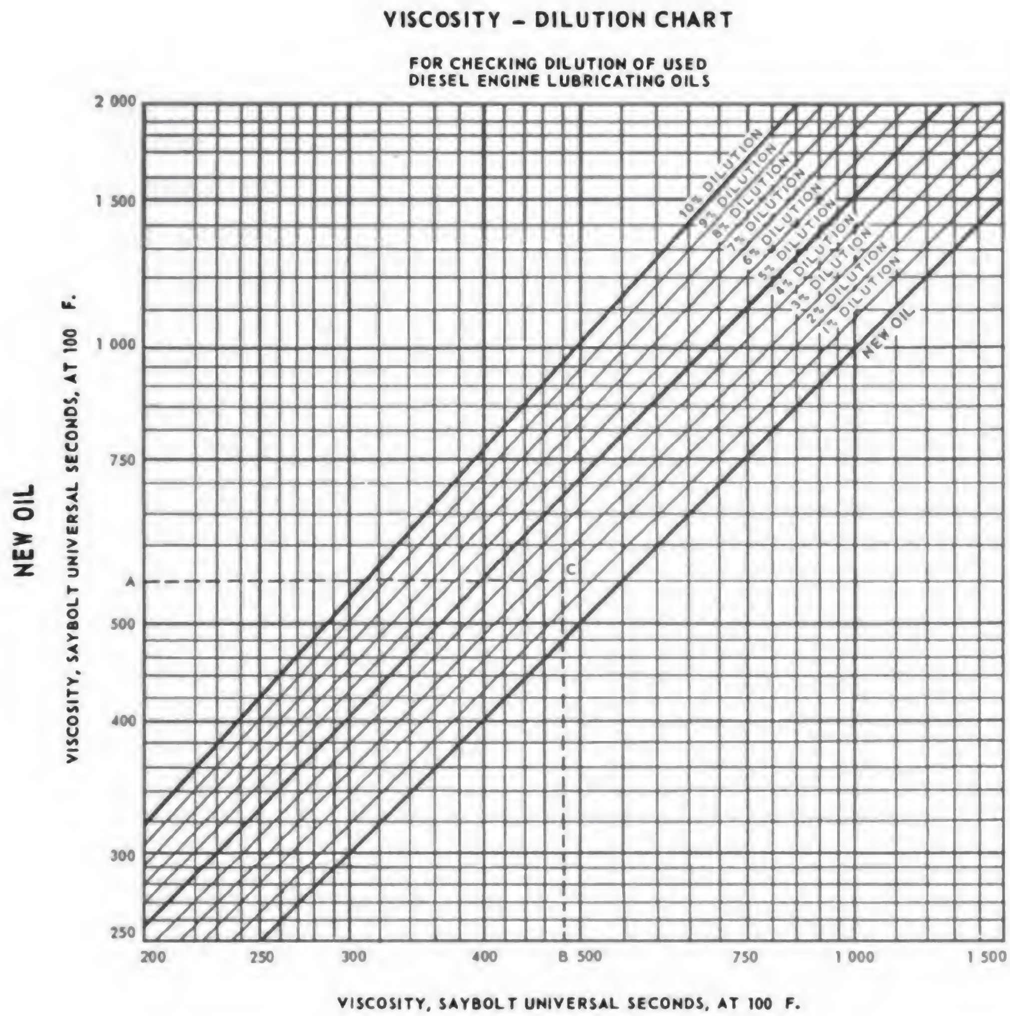


Figure 9–3.—Lubricating oil dilution chart.

changed sooner—if the mechanism is operating under heavy load, or if you are preparing for a long run and may not get a chance to change the oil.

CONVERSION OF UNIVERSAL AND FUROL.—Viscosity of lubricating oil is always expressed in Seconds, Saybolt Universal. However, in fuel oil testing, viscosity is expressed in Seconds, Saybolt Furol, or in Seconds, Saybolt Universal; therefore, it may become necessary to convert from SSF to SSU. For practical purposes, viscosities between 50 and 100 SSF can be converted into SSU, by multiplying by 10. Below 50 Seconds Furol, the Universal seconds can be determined by referring to a table such as is shown in figure 9–4.

Saybolt Universal (Seconds)	Saybolt Furol (Seconds)
200	23.0
220	25.3
240	27.0
260	28.7
280	30.5
300	32.5
325	35.0
350	37.2
375	39.5
400	42.0
425	44.2
450	47.0
475	49.0
500	51
550	56
600	61
650	65
700	71
750	76
800	81
850	86
900	91
950	96
1000	100
1200	121
1400	141
1600	160
1800	180
2000	200
2500	250
3000	300
3500	350
4000	400
4500	450
5000	500
5500	550
6000	600
6500	650
7000	700
7500	750
8000	800
8500	850
9000	900
9500	950
10000	1000

Figure 9–4.—Approximate viscosity equivalents at the same temperature.

PRECAUTIONS IN USING VISCOSIMETER.—The precautions to be taken in using a Saybolt viscosimeter are as follows:

1. Clean the tube properly before each test.
2. Don't use a drill, or other hard instrument, in the small outlet jet on the tube proper. If it becomes necessary to rid this jet of foreign matter, a piece of plaited fishing line may be pulled lightly back and forth in the jet.
3. Keep the tube covered when the instrument isn't being used.
4. Remove soot by boiling the tip of the heater in water, taking care not to wet the electrical connection. After boiling, the soot can easily be rubbed off.
5. See that the temperature of the bath is not raised higher than the scale of the thermometer in use.

Pour Point

The lowest temperature at which an oil will barely flow from a container is known as the POUR POINT. This property is closely related to viscosity, and the paraffin content; an oil of high viscosity will have a higher pour point than one of low viscosity, and the higher the paraffin content, the higher the pour point. In cold weather an oil having a high viscosity may be difficult to pump through the lubrication system of an engine, thus causing starting difficulties. The pour point is especially important for oils used with refrigeration units and internal-combustion engines.

Flash and Fire Points

The temperature at which enough vapor is given off to flash in the presence of a spark or momentary flame is known as the FLASH POINT. The minimum flash points allowed for lube oils used by the Navy are above 315° F, and the lube oil temperatures will always be much lower unless something goes wrong. (In that case, you will shut down before the temperature becomes dangerously high.)

The flash point of an oil may be determined by either the OPEN-CUP or the CLOSED-CUP method. The flash point obtained with the open-cup apparatus is generally about 10° F above that obtained from a closed-cup test.

OPEN-CUP TEST. The simpler method of determining the flash point employs the open-cup tester. This apparatus consists of a small uncovered vessel, a heating unit, and a thermometer. When determining the flash point by this method, draw a fresh sample of the oil immediately before starting the test. Strain it through a felt strainer to remove any free moisture and then place about 75 cc of the oil in the open-cup tester. See that the oil covers the bulb of the thermometer. Heat rapidly to about 100° F and then raise the temperature gradually (about 10° per minute) to 150° F. At frequent intervals, pass a lighted taper over the mouth of the cup and note the temperature at which a flash occurs. This temperature is the FLASH POINT of the oil.

CLOSED-CUP TEST.—In general, the Navy employs the closed-cup method to determine the flash point of fuel oils; the apparatus used is the Pensky-Marten tester. In this apparatus, shown in figure 9–5, the cup (oil container) has a tightly fitting lid. It rests in a cast-iron jacket which is provided with a brass mantle to reduce radiation. An orifice in the lid of the oil cup can be opened by means of a knob, and the small lighted taper can be dipped into this opening, for igniting the vapor. The stirring paddles are operated by the flexible stirring shaft.

Before a test is made, all water must be removed from the oil by filtering the oil through a small felt filter. When the sample is ready, the oil cup is filled to the mark on the wall of the cup, the cover is placed in position, and heat is applied until the rate of temperature increase is from 9° to 11° F per minute. The handle, or stirring shaft, is turned continuously and slowly. At intervals of 5° F rise in temperature, the knob is rotated, thus opening the shutter and tilting the flame into the cup. As

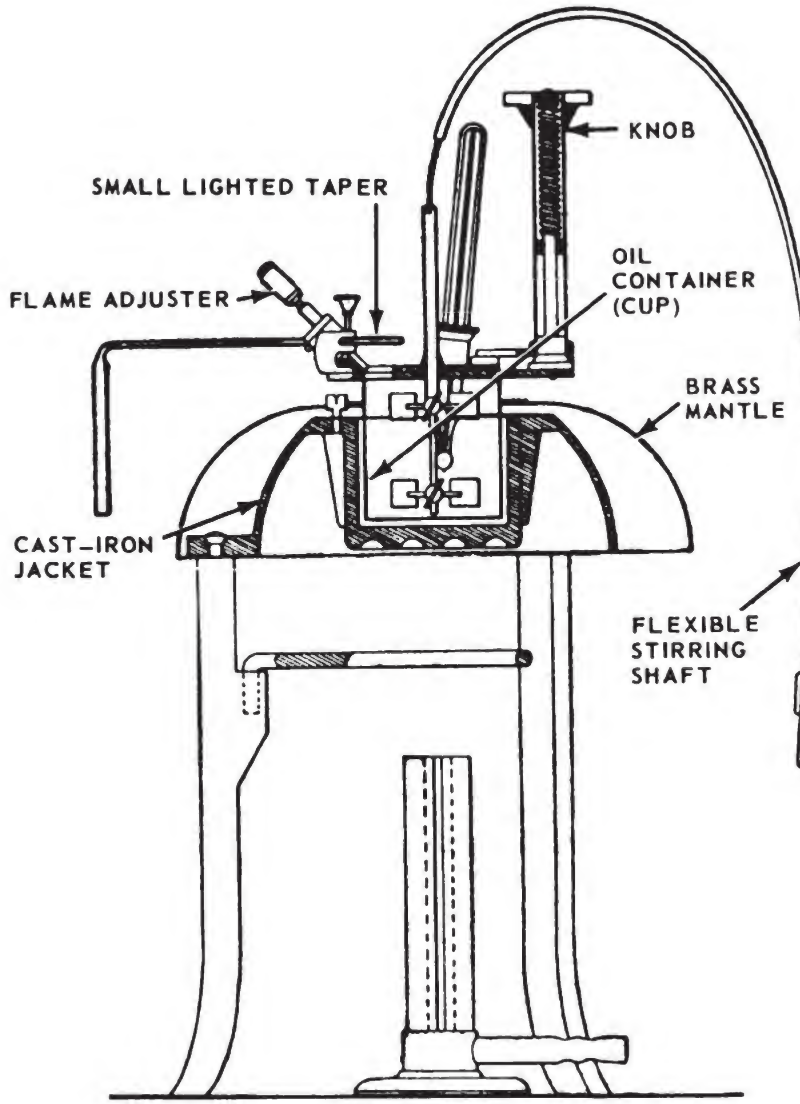


Figure 9–5.—Flash-point tester.

the expected flash point is closely approached, the test should be made at every 2° F rise in temperature.

The flash point is the temperature at which a slight explosion occurs, and should not be confused with the bluish halo that may surround the test flame. A sample should NOT be used for a second test, because some of the more volatile products are driven off during the first test.

However, the same sample may be used to determine the FIRE POINT by continuing to pass the taper back and forth until the oil catches fire and remains burning. The

lowest temperature at which this continual burning takes place is known as the FIRE POINT of the oil.

Autogenous Ignition Point

The temperature at which flammable vapors given off from an oil will burn without the application of a spark or flame is known as the AUTOGENOUS IGNITION point. For most lubricating oils, the autogenous ignition temperature is approximately 650° F.

Ignition Quality of a Fuel (Cetane Number)

One of the most important properties of a Diesel fuel is the ignition quality, expressed by an index known as the CETANE NUMBER. It is a measure of the ease of ignition, and indicates the kind of combustion which will be obtained from the fuel. Present high-speed Diesel engines require fuels with a cetane number of about 47. As the cetane number is increased, easier starting is obtained, even at low temperatures, together with quicker warm-up, smoother operation, lower maximum pressures, and lower fuel consumption.

Cetane is a member of the hydrocarbon group of chemical compounds (hydrogen and carbon are the chief elements which form all these compounds), and in its pure state is an excellent Diesel fuel. Alpha-ethyl-naphthalene is another member of the same family but has very poor ignition characteristics.

The scale of cetane numbers runs from 0 to 100, pure cetane being at the top, and alpha-methyl-naphthalene being at the bottom of the scale. For example, a cetane number of 55 indicates a mixture equivalent to one consisting of 55 percent cetane and 45 percent alpha-methyl-naphthalene.

A special single-cylinder test engine, with a variable compression ratio, is used to determine the cetane number of a fuel sample. The test procedure is based on the fact that the ignition-delay period in a given engine, at a fixed speed, decreases with an increase in the compression

ratio. (The delay period is measured from the time the fuel injection valve leaves its seat until a measurable pressure rise is produced in the cylinder.)

The test fuel is burned in the engine, and the compression ratio in the engine is raised until the standard ignition-delay period (13 crank-angle degrees), taken as a reference, is reached. After the compression ratio for the test fuel is determined, the engine is run with various mixtures of cetane and alpha-methyl-naphthalene. When a mixture is obtained which requires the same compression ratio as the test fuel for the standard ignition delay, the percentage of cetane in this mixture is the cetane number of the test fuel.

Disadvantages of Gasoline as Diesel Fuel

Tests have shown that a Diesel can run on gasoline, although the engine operation will be noisy and rough. In addition, the fuel consumption will be higher than with regular Diesel fuel oil. By adding 10 to 15 percent of regular Diesel fuel oil to the gasoline, the performance of the engine can be improved considerably. Despite the fact that gasoline can serve as a Diesel fuel, it should NOT be used without specific authority because of the potential hazards associated with its use.

Another disadvantage of running a Diesel engine on gasoline is the danger of wear and seizure of the fuel-injection pumps because of the low viscosity of the gasoline.

Demulsibility

The ability of an oil to separate cleanly from any water present is referred to as DEMULSIBILITY. Straight mineral and most compound oils have satisfactory demulsibility characteristics, especially when the oils are fresh. Additives in heavy-duty Diesel engine lube oil, however, tend to keep water dispersed in the oil. Therefore, care must be taken to see that water does not enter the lube oil of a Diesel engine.

Water and Sediment

As an Engineman 2, you must know the procedure for determining the amount of water and sediment in both fuel oil and lubricating oil. To perform this test, you use the principle of CENTRIFUGAL FORCE, which you studied in the Navy training course, *Fireman,* NavPers 10520-A. When a substance is whirled or rotated about a center, it

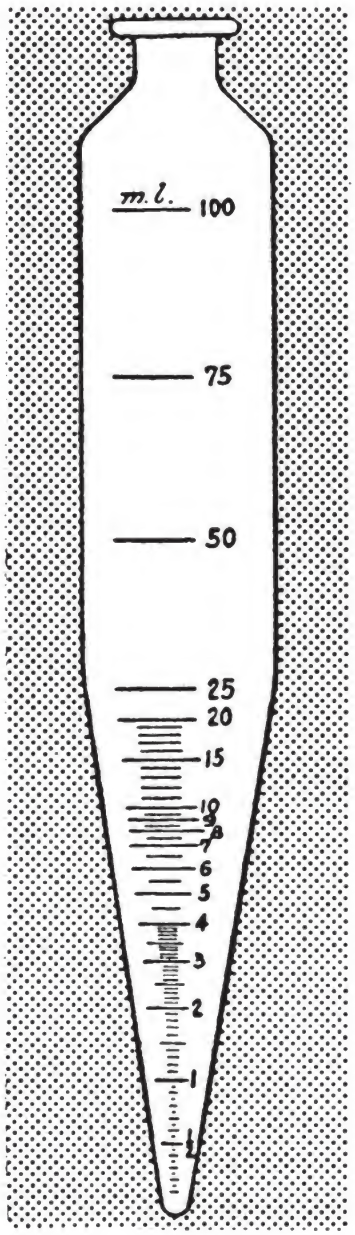


Figure 9-6.—Centrifuge tube.

tends continuously to fly off in a straight line in the direction in which it is traveling at any particular moment. The heavier the object, or the faster the rotation, the greater is the centrifugal force. If mixed liquids, or liquids containing substances of various weights, are whirled in a container, the heavier materials will work to the outside of the container. (This fact is illustrated in a cream separator, which whirls the heavier milk to the outside of the instrument, collecting the lighter cream at the inside.)

Water and sediment in oil are heavier than the oil. If the oil containing water and sediment is whirled, the water and suspended solids will go to the outside. The instrument which tests the oil is known as a CENTRIFUGE; it is used to whirl test tubes filled with samples of the oil containing water and sediment so that the oil can be separated from the water and sediment.

The tubes are either pear- or cone-shaped bottles designed to fit into rubber seats, or jackets. If the centrifuge mechanism is equipped with more than two jacket spaces, see that the tubes are arranged exactly opposite each other so that the balance of the mechanism will be preserved while it is rotating.

The tubes are graduated, or marked, in milliliters (ml) and tenths of a milliliter, and hold 100 ml each. A centrifuge tube, illustrated in figure 9–6, is graduated from top to bottom as follows:

Range (milliliters)	*Scale of divisions (milliliters)*	*Numbered (milliliters)*
0–4	0.1	0.5, 1, 2, 3, 4
4–10	0.5	5, 6, 7, 8, 9, 10
10-20	1.0	10, 15, 20
20–25	5.0	20, 25
25–100	25.0	25, 50, 75, 100

In testing for bottom sediment and water, proceed as follows:

1. Measure 50 ml of 90 percent benzol into each of two centrifuge tubes, and add to each tube 50 ml of the oil to be tested.
2. Close the tubes tightly and shake vigorously until the contents are thoroughly mixed.
3. Place the tubes in a water bath, maintained at 120° F, and leave the tubes immersed therein (to the 100-ml mark on the tube) for 10 minutes.
4. Place the tubes opposite each other in the centrifuge and rotate them for 10 minutes.
5. Read and record the combined volume of water and sediment at the bottom of each tube. (If necessary, estimate to 0.1 ml.)
6. Replace the tubes in the centrifuge, repeat the whirling for 10 minutes, and remove for reading the volume of water and sediment as before. Repeat this operation until the combined volume of water and sediment in each tube remains constant for three consecutive readings.
7. Read the combined total volume of water and sediment in each tube, and estimate to 0.1 ml, if necessary. The sum of these two readings should be recorded as the percentage of the water and sediment in the oil.

With care and attention to details, duplicate determinations of water and sediment by this method should not differ by more than 0.2 ml.

Specific Gravity

The ratio of the weight of a given volume of any substance in air to the weight of an equal volume of water is known as the SPECIFIC GRAVITY of the substance. For a liquid, the specific gravity is determined by using a hydrometer—a small glass instrument which looks somewhat like a thermometer. This instrument is immersed in a glass container of the liquid and the specific gravity is read directly from the hydrometer scale at the level of the liquid.

The A. P. I. scale is the standard used to measure the specific gravity of the oil. When it becomes necessary to test an oil for specific gravity, make certain that the oil is thoroughly stirred and that no air bubbles are present. In addition, see that all materials are clean, and that instrument, oil, and container are all at room temperature.

Ash Content

Whenever an oil is burned, a small amount of ash remains. This ash, the unburnable part of the oil, may cause abrasion or scoring of the moving parts with which it comes in contact. It is important, therefore, to know the ash content of an oil. Ash content must be determined in a laboratory and will be shown on the delivery receipt for oil taken aboard.

RECOMMENDED OILS

Lubricating oils used by the Navy are classified by a system of symbols. Each symbol consists of four numbers, the first identifying the oil according to use, and the last three indicating the viscosity.

Selection of the proper lubricant is extremely important, because each unit should be supplied with the oil best suited to its operating conditions, speed, size, and bearing pressure. Proper selection is also of importance in that all similar units should use the same grade of oil; this will reduce the variety of grades to be carried in stock, and will decrease the number of mistakes in delivery and mixing of dissimilar oils in tanks. Manufacturers' instruction books and the list of lubricants on board, if provided, should be consulted for the proper Navy symbol oil for specific equipment.

There are nine classes, or series, of Navy lubricating oils. These classes are of two general types: the MINERAL TYPE, and the COMPOUNDED, or ADDITIVE TYPE. The mineral type oils (classes 1, 2, 3, and 5) are petroleum oils derived from crude oil. The compounded, or additive, oils (classes 4, 6, 7, 8, and 9) are petroleum oils with

special ingredients added. According to classification within the two general types, the nine classes are given in the paragraphs which follow.

Mineral Oils

1000 SERIES. The aviation engine oils include Navy Symbol Nos. 1065, 1080, 1100, 1120, and 1150. Navy Symbol Nos. 1100, 1120, and 1150 oils are of primary concern to an Engineman. Navy symbol 1100 and 1120 oils are used in the Packard engines of PT ships, and symbol 1150 (SAE 70), is used in the compressors of some distilling plants.

2000 SERIES. The forced-feed oils (viscosity measured at 130° F) consist of Navy Symbol No. 2075 to 2250, inclusive; Navy symbol 2075 H; Navy symbol 2110 H, Navy symbol 2135 H, and Navy symbol 2190 T, turbine oil. Although Navy Symbol Nos. 2075H, 2110 H, 2131 H, and 2190 T contain additives, their uses place the oils in class 2. The additive materials increase the oil's ability to displace water from steel, prevent oxidation, and for the Navy Symbol No. 2190 T oil, the additive adds extra load carrying ability. Manufacturers of ball bearings generally specify that bearings for the turbine-driven auxiliaries must be lubricated with Navy Symbol No. 2190 T oil.

3000 SERIES.—The forced-feed oils (viscosity measured at 210° F) consist of symbols 3042 to 3150, inclusive. Most internal combustion engines use lubricating oils in the 9000 series. However, in large Diesel engines having circulating systems with separately lubricated cylinders and water-cooled pistons, Navy symbol 3065 should be used for lubricating bearings. Aircraft rescue boats (Hall-Scott gasoline engines) use oil in the 3000 series. Navy symbol 3080 is used in the oil system of all turbine-driven pumps incorporating worm gears.

5000 SERIES.—The mineral marine-engine and cylinder oils include symbols 5150, 5190, and 5230. Oils in this class, or series, were developed for machinery with steam

cylinders, where an oil must not only withstand high temperatures but must also have good demulsibility.

Compounded, or Additive Oils

Compounded marine-engine and cylinder oils contain varying amounts of additives which improve the ability of the oils to lubricate in the presence of water and steam. Because of their emulsibility, Navy symbol oils 4065, 6135, 7105, and 8190 should never be used in a forced-feed circulating system.

4000 SERIES.—Symbol 4065 is a compounded marine-engine oil (viscosity measured at 210° F). This oil emulsifies quickly when mixed with water, and forms a lather which will not wash off metal surfaces as readily as a straight mineral oil.

6000 SERIES.—Symbol 6135 is a compounded steam cylinder oil (viscosity measured at 210° F). This type of oil is used, at ambient temperatures of 40° to 160° F, on enclosed worm gears where lubrication is by splash, and on open worm gears where application is by brush or paddle.

7000 SERIES.—Symbol 7105 is a compounded steam cylinder oil (viscosity measured at 130° F). This type of oil is applied to the same kind of equipment as symbol 6135; however, it is used when the ambient temperature ranges from 0° to 40° F.

8000 SERIES.—Symbol 8190 is a compounded air-cylinder oil (viscosity measured at 130° F). When the air is moist, this oil is used on the valves and cylinders of air compressors and pneumatic tools.

9000 SERIES.—These oils are developed for the lubrication of high-speed, high-output Diesel engines. These oils are compounded with additives which prevent sludge formation and carbon deposits. They also contain detergents for keeping the engines clean. The use of these additive oils has been extended to most types of internal combustion engines. Some exceptions have already been given under the discussion of the 1000 and 3000 series.

The detergent oils suitable for heavy duty lubricating purposes are represented by the symbols 9110, 9170, 9250, and 9370 (viscosity measured at 130° F), and by symbol 9500 (viscosity measured at 210° F). These oils should be used in accordance with the viscosity specified for particular equipment. The equivalent SAE numbers for 9000 series oils are as follows: SAE 10(9110), 20(9170), 30(9250), 40(9370), and 50(9500).

INSPECTION OF LUBRICATING OIL SYSTEM

In the event that you are to start a Diesel engine which has been idle for a long period of time, or overhauled, you should first inspect the lubricating oil system, as follows:

1. Fill the oil sump to the proper level. If possible, take a sample of lubricating oil and check it for dilution. In addition, take a sample from the bottom of the sump to determine if any water is present. Remove any water found by running all the oil through the purifier, if provided. Where a separate filtering system is provided, the oil may be cleaned by circulating it through the filtering system. However, this should not be done until the oil is in a heated condition. Where the installation permits, the oil should be heated to a temperature of at least 100° F, prior to starting the engine.
2. Fill all grease cups and lubricators, where provided.
3. See that hydraulic governors, where provided, are filled to the proper level with the specified grade of lubricating oil.

In addition to inspecting the lube oil system before starting a Diesel engine, you should perform the following checks during the normal operating routine:

1. See that the mechanical oilers, where provided, are feeding properly and not becoming air-bound.
2. Check the oil level in the sump frequently; the oil should be replenished, when necessary.

3. Operate the lubricating oil purifiers, where provided, whenever the engines are in use, and periodically during idle periods. Lubricating oil filters should be checked frequently and the cartridges replaced when necessary.
4. Rotate the cleaning handle on all lubricating oil strainers at least two complete revolutions once each watch.
5. Check the viscosity of the lubricating oil, at least once each day, to determine the percent of fuel dilution.

SUMMARY

It is important for you, as an EN 2, to know the procedures used to determine the viscosity, cetane number, fire and flash points, and water and sediment content of fuel and lubricating oils.

A satisfactory oil for engine use must have a viscosity which remains within suitable limits throughout the operating temperature range of the engine. In addition to maintaining a sufficient oil film between the moving parts, the oil must leave a minimum of carbon residue, be stable, and resist oxidation, acidity, and emulsification.

It is important for you, as an EN 2, to know what types of lubricating oils are used by the Navy, how the various oils are classified and identified, and what instructions you must follow in determining the correct lubricant for each equipment.

QUIZ

1. What is viscosity of an oil?
2. In stating the viscosity, what factors are indicated in addition to the type of viscosimeter used?
3. How do the Saybolt Furol Viscosimeter and the Saybolt Universal Viscosimeter differ?
4. When using a Saybolt Furol Viscosimeter to test the viscosity of a sample of oil, what temperature should be maintained?
5. When an engine is running, how is the viscosity of the lube oil generally affected?

6. When a visgage is used to check viscosity, what should be the approximate temperature of both the sample oil and the standard oil?
7. When the trial tube of a visgage has been filled with oil, what is the next step in getting a viscosity reading?
8. Under normal conditions, when should a lube oil be changed?
9. What is the pour point of an oil?
10. The flash point of an oil can be determined by what two methods?
11. What is the fire point of an oil?
12. Why is an oil sample used in determining flash point by the Pensky-Marten tester of no value for a second test?
13. The temperature at which flammable vapors given off from an oil will burn without spark or flame being applied is known as what point?
14. How is the starting of an engine affected when the cetane number of a Diesel fuel is increased?
15. What type of equipment is used to determine the cetane number of a fuel sample?
16. The test procedure used to determine the cetane number of a fuel sample is based on what fact?
17. Why should gasoline NOT be used as Diesel fuel?
18. What is the demulsibility of an oil?
19. Why is a centrifuge test used on oil?
20. What is the unburnable part of an oil called?
21. How are Navy lubricating oils classified?
22. Into what two general types are the nine classes of Navy lubricating oils divided?
23. What type aviation engine oil is recommended for use in distilling plant compressors?
24. Why are additives present in the 4000 series marine engine and cylinder oils?
25. Most internal combustion engines use lubricating oils in which series?
26. When the air is moist, what oil is used on the valves and cylinder of air compressors and pneumatic tools?

CHAPTER 10

GAS TURBINE ENGINES

As an Engineman 3, you probably operated and maintained reciprocating type internal combustion engines—Diesel and gasoline. In the future, however, you may come in contact with a different type of internal combustion engine—the gas turbine. At this point, it would probably be helpful for you to review the Navy training course *Engineman 3*, NavPers 10539, which covered the components and operating principles of a two-stage gas turbine engine.

This chapter will stress the principal system of a two-stage gas turbine engine, as well as the operation and maintenance of this type engine.

NAVY USE OF GAS TURBINE ENGINES

Although the gas turbine engine is not new, its application to marine use in the Navy is relatively recent. The MSB–5 class minesweepers were the first US naval vessels to use gas turbine engines, manufactured by Boeing, on an operational basis. Additional applications of the gas turbine engine have been made on an operational basis, and as service experience has been gained, the number of gas turbines in use has increased.

The gas turbine is unique because its functional simplicity gives it various advantages over other types of power plants. With respect to fuel consumption, however, the simple-cycle gas turbine engine cannot compete

with the Diesel engine because it is limited in the use of efficiency-improving auxiliary devices which are available to larger plants. The field of use, therefore, even for a lightweight gas turbine plant, is limited to applications in which the inherent advantages of a gas turbine are more important than fuel consumption. Such applications may employ one or more of the following characteristics:

1. Minimum weight (pounds per horsepower output).
2. Minimum volume to conserve space.
3. Smooth, vibration-free operation.
4. Utilization of exhaust heat for de-icing or smoke generation.
5. Quick starting without warmup time.
6. Rapid adjustment to varying loads.

The Solar T–520–522 series gas turbine (500 horsepower drive, constant or variable speed) is an example of the functional simplicity inherent in naval gas turbine power plants. Three constant-speed T–520 gas turbine engines are now in use and performing satisfactorily. Two of these units are used as minesweeping generator prime movers aboard the MSB–28, and one is used aboard the USS *Timmerman* (EAG–152) as a prime mover for the forward emergency generator.

The Solar model T–520–522 series consists of a 10-stage axial flow compressor designed with a tapering rotor tip diameter supplying a single, conventional can-

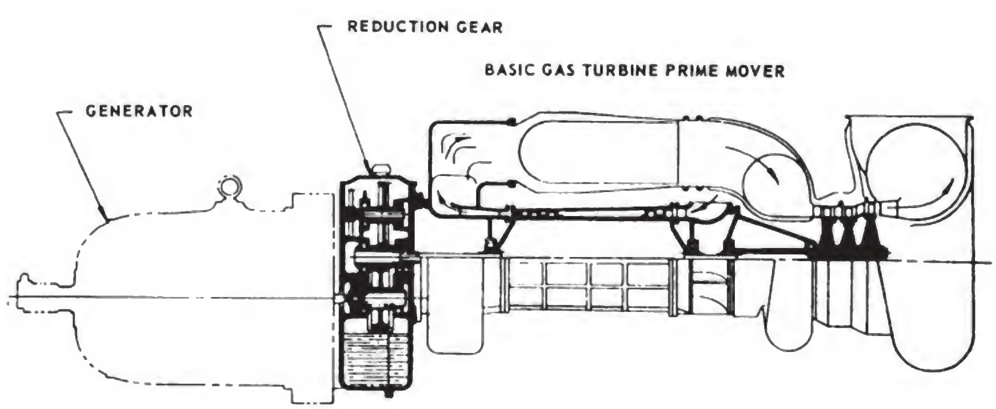


Figure 10–1.—Model T-520 constant speed gas turbine.

type combustor which parallels the compressor for efficient use of space. Hot gas from the combustor is supplied to a 3-stage axial flow turbine. The third stage turbine is directly connected with the first 2 turbine stages for the direct-drive unit (fig. 10–1).

For the variable output speed gas turbine, the third stage is not mechanically connected to the first two stages, and the output power is taken from the third stage through a suitable reduction gear box (fig. 10–2).

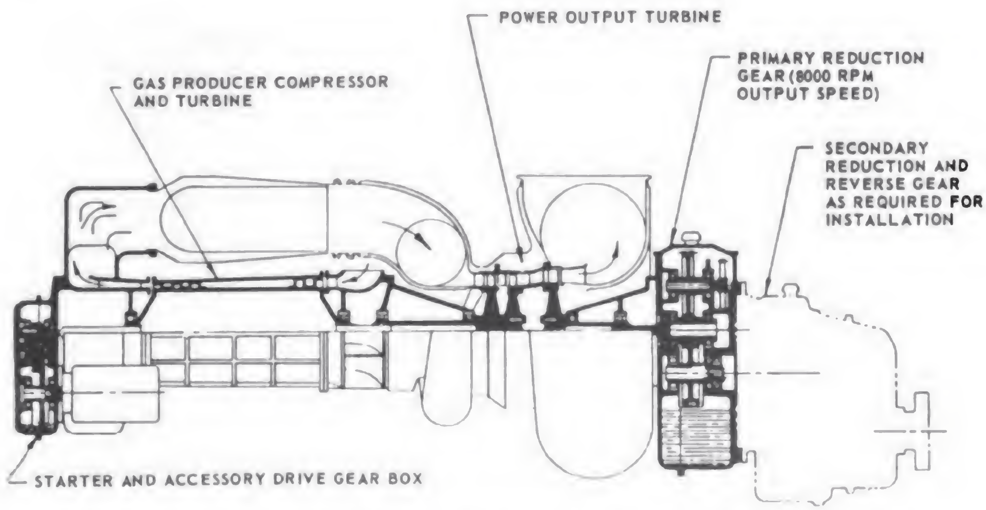


Figure 10–2.—Model T-522 variable output speed gas turbine.

The basic features of the 500-horsepower gas turbine are as follows:

1. Engine weight is less than 1 pound per horsepower.
2. Dimensions are 60 inches by 32 inches by 40 inches.
3. No reciprocating parts.
4. Diesel fuel, kerosene, or jet fuel can be burned.
5. Adaptable to a 10-second or less starting time and requires no warmup time for the engine.
6. Adaptable to production manufacturing.
7. Requires no engine cooling water.
8. Torque of 3,150 foot-pounds at zero output shaft rpm.
9. Low lube oil consumption as well as low lube oil capacity.

The performance characteristics of the gas turbine are as follows:

- Ambient air temperature ....80° F
- Turbine inlet temperature ....1,500° F
- Maximum rotational speed of compressor and turbine (all stages) ....20,000 rpm
- Compressor air flow rate ....8.26 pps
- Compressor pressure ratio ....4.87 to 1
- Rated gear box shaft output (continuous) ...521 hp
- Specific fuel consumption (continuous hp) .... .92 lb/hphr

The design life of a gas turbine power plant can be predicted by analyzing such factors as stress rupture, creep, and fatigue life of the material used. However, some indication of the life expectancy of components like turbine blades, gears, and bearings can be calculated from the operational data obtained from similar gas turbine engines. Major overhaul periods for the T–520–522 engines are now set at 1000 hours.

It is predicted that, in the near future, the fuel consumption of the Solar T–520 engine will be reduced to approximately 0.8 pound of fuel per horsepower hour, and the power will be increased to 600 horsepower. The addition of a lightweight regenerator to this engine would increase the specific engine weight from approximately 1 to 2 pounds per horsepower. In addition, a decrease in specific fuel consumption from 0.8 to 0.6 pound of fuel per horsepower hour would result.

PRINCIPAL SYSTEMS AND COMPONENTS OF A TWO-STAGE TURBINE ENGINE

The principal systems and components of gas turbine engines discussed in this chapter are applicable to the engines (Boeing 502) of the unit shown in figure 10–3. Even though gas turbine engines vary in design, and future installations may include engines of other manufacturers, most of the discussion in this chapter will still be applicable.

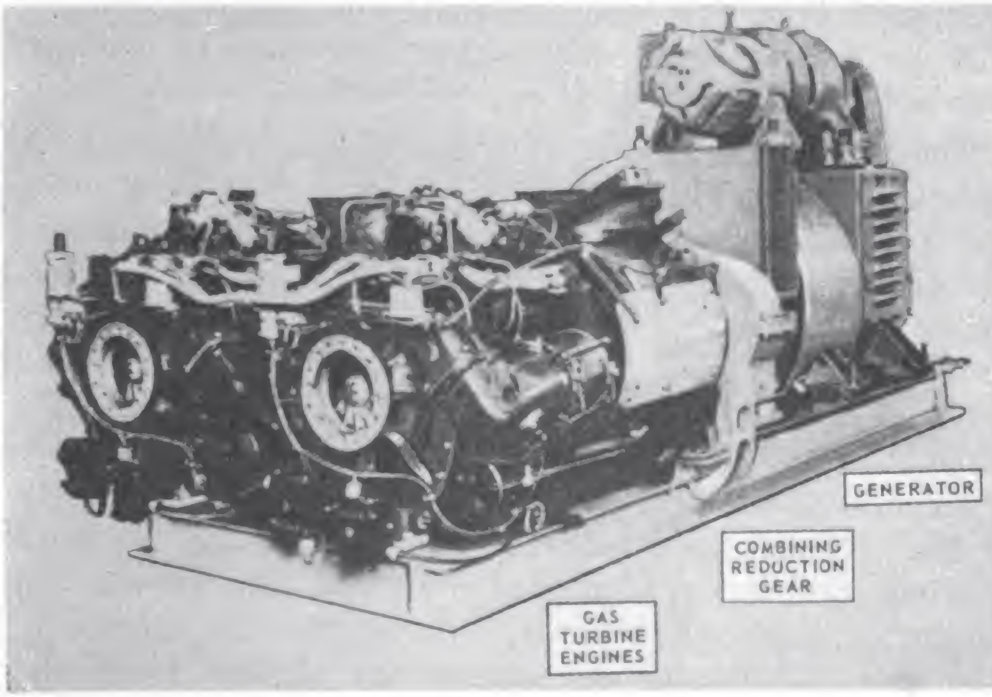


Figure 10–3.—Gas turbine-generator unit.

Gas turbine installations, aboard the MSB–5 class minesweepers, supply motive power for the generators in minesweeping operations. The engine generator unit (turbine-generator power package) used for this purpose is shown in figure 10–3. The gas turbine installation consists of two gas turbine-generator units, and each unit consists of two gas turbine engines, a combining reduction gear, and a d-c generator, mounted on a rigid rectangular frame. Each engine is coupled to a separate input shaft of the combining gear. The overrunning clutch permits single engine operation of the power package.

The engines of the unit shown in figure 10–3 are divided into two sections or stages: a gas producing section (first stage) which is basically a simple jet engine, and a power output section (second stage) which converts some of the energy of the combustion gases into useful power as required by the electrical load. Although both engine sections are attached to a casting that forms the engine

base, each is mechanically separate and coupled together only by an interconnecting duct that confines the gas flow between the two sections.

The gas producing section consists of a centrifugal air compressor, two cross-connected through-flow type burners, a nozzle box, an axial flow turbine, and an accessory-drive unit. The compressor consists of a rotating impeller enclosed in a case which has diffusing vanes on its inner surface. The impeller is secured to the extended shaft of the turbine wheel to form the rotor assembly of the engine. This turbine wheel is driven by the flow of expanding gases created by burning fuel continuously in the combustion chambers. Pressurized air for supporting combustion is produced by the compressor and conducted, through separate elbows, to the chambers. The essential engine accessories are driven from the rotor shaft through a gear system.

In the power output section, the wheel of a second axial flow turbine drives the splined output shaft through double reduction gearing. This turbine wheel is driven by the flow of combustion gases from the first stage of the engine. These gases normally discharge into the turbine exhaust duct aft of the second-stage wheel. During reduced load (which would increase the speed output), some of the gases are released, through an outlet ahead of the turbine, into an interstage bleed duct. For all variations in generator load, a gate type valve, in each of two ducts, controls the flow of combustion gases through the second-stage turbine, as required, to maintain a constant output shaft speed. These gate valves are linked to a hydraulically-actuated piston by a speed-sensitive governor. The speed of the second-stage wheel and output shaft is limited by a centrifugal switch which automatically stops the engine in the event of over-speed.

Power from the two gas turbine engines is combined to drive the generator at reduced speed through a combining reduction gear. The latter consists of two pinions

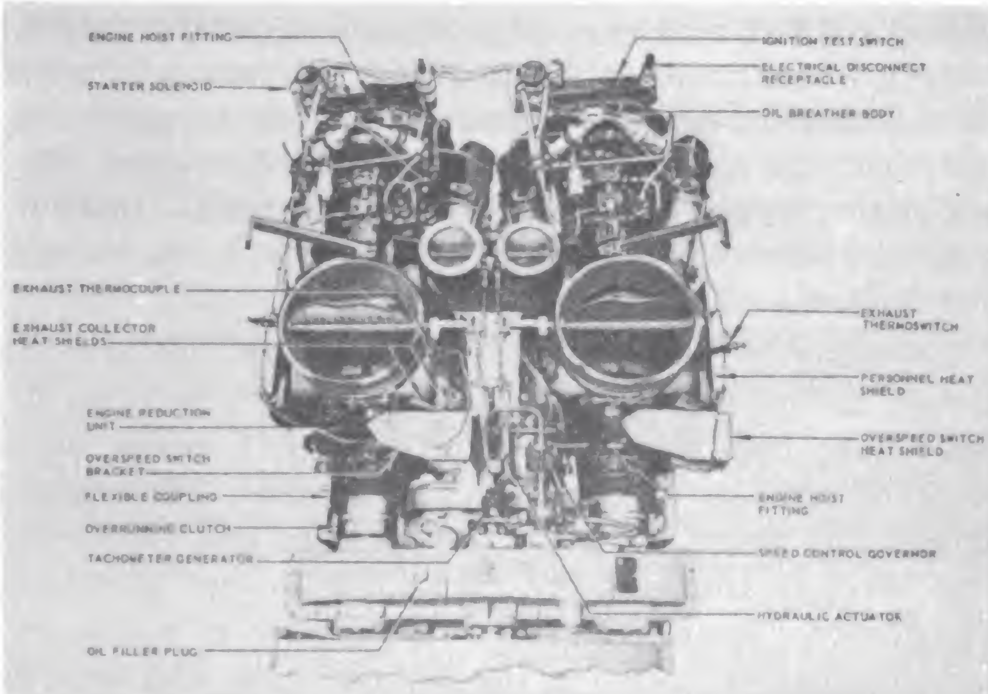


Figure 10–4.—Engines and combining gear.

and a main gear enclosed within a cast housing. The pinions are driven by the turbine engines and mesh with the main gear, which drives the generator. Additional internal gearing drives four pad-mounted accessories on the input end of the gear housing.

The general arrangement of the gas turbine engines and the combining gear components is shown in figure 10–4. Specific information on a particular engine unit, or components, may be found by referring to the appropriate manufacturer's instruction book. The principal systems of a gas turbine engine, however, will be discussed in this section of the chapter.

FUEL OIL SYSTEM

The principal system of a gas turbine engine which supplies fuel for combustion is the fuel oil system. This system consists of an engine-driven pump, high-pressure filter, fuel control governor, nozzle, shutoff valve, pressure gage, starting fuel-bypass valve, starting fuel-bleed

orifice, and two nozzles. (A schematic view of a fuel oil system is illustrated in figure 10–5.) A manual shutoff valve, filter, and supply pump are in the fuel supply manifold line, and a similar manual shutoff valve and filter are in the supply line to each power package. In addition, a separate shutoff valve is provided in the supply line to each engine.

Referring to figure 10–5, the fuel flows through the system as follows: The engine-driven pump receives filtered fuel from the motor-driven supply pump at a constant pressure of approximately 15 psi. The engine-driven fuel pump increases the pressure and forces the fuel through the high-pressure filter to the governor. The governor meters the fuel to the nozzles, as necessary, to maintain combustion at the required rate, and returns the excess fuel to the inlet port of the engine-driven pump.

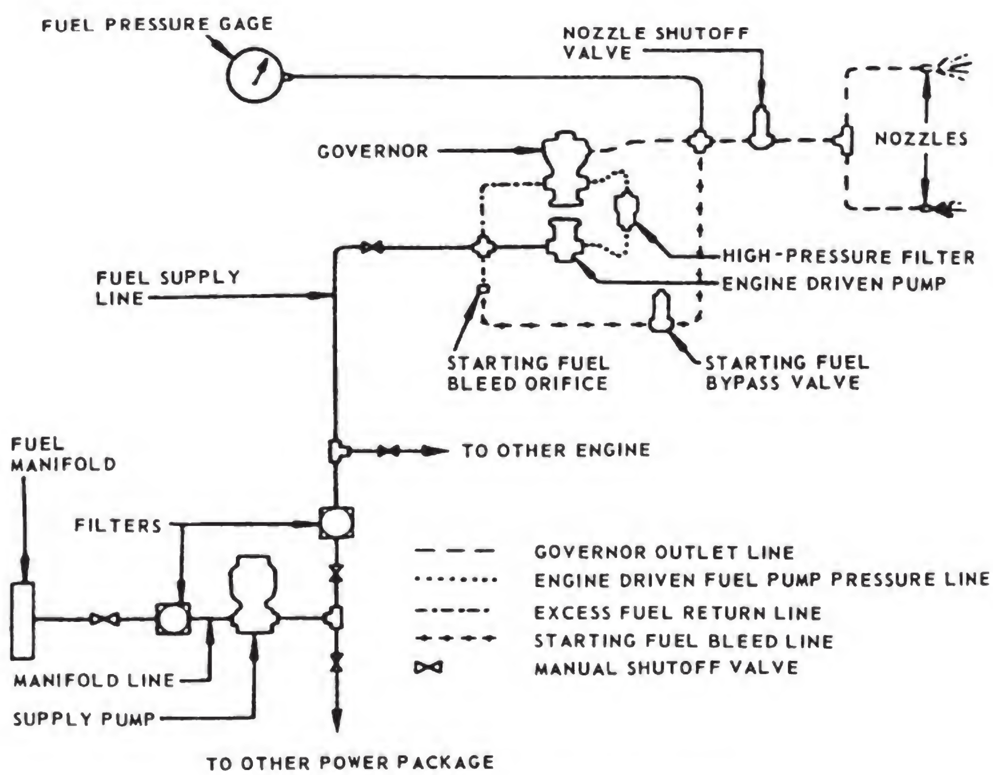


Figure 10–5.—Schematic fuel flow diagram.

The fuel nozzle shutoff valve is installed in the line between the governor and the fuel nozzles. The fuel-pressure gage, on the engine control panel, is connected to the line between the governor outlet and the nozzle shutoff valve. During engine cranking, fuel nozzle pressure is maintained (between 50 and 150 psi) by bleeding excess pressure from the governor outlet line to the inlet port of the engine-driven fuel pump. The starting fuel-bypass valve opens the governor outlet line, which contains an orifice that determines the amount of bleed.

VALVES.—A disk type shutoff valve, installed in the line between the governor outlet port and the fuel nozzles, is mounted on a bracket attached to the left side of the accessory-drive unit. (The direction of fuel flow is indicated by an arrow on the housing.) When the valve is closed, it shuts off the flow of fuel to the nozzles.

A solenoid, screwed into the top of the valve body, encloses a spring-loaded plunger, which forces the valve disk against the shutoff port. By unlocking the throttle after a cranking speed of approximately 5000 rpm is attained, the solenoid is energized and the plunger raised. This action causes the disk to lift from the shutoff port and allows metered fuel flow from the governor to the nozzles.

The starting fuel-bypass valve, identical to the fuel nozzle shutoff valve, is attached to a bracket on the right side of the accessory-drive unit (fig. 10–6). This valve is a disk type, solenoid actuated valve installed in the fuel-bypass line, between the governor outlet and the inlet port of the engine-driven fuel pump. The starting fuel-bypass valve is open only while the starter switch is closed, preventing excessive pressure from building up (during engine starting) in the governor outlet line.

FILTERS.—A high-pressure filter is located between the outlet port of the engine-driven fuel pump and the inlet port of the governor. The filter consists of a two-piece housing, a replaceable micronic cartridge, and an

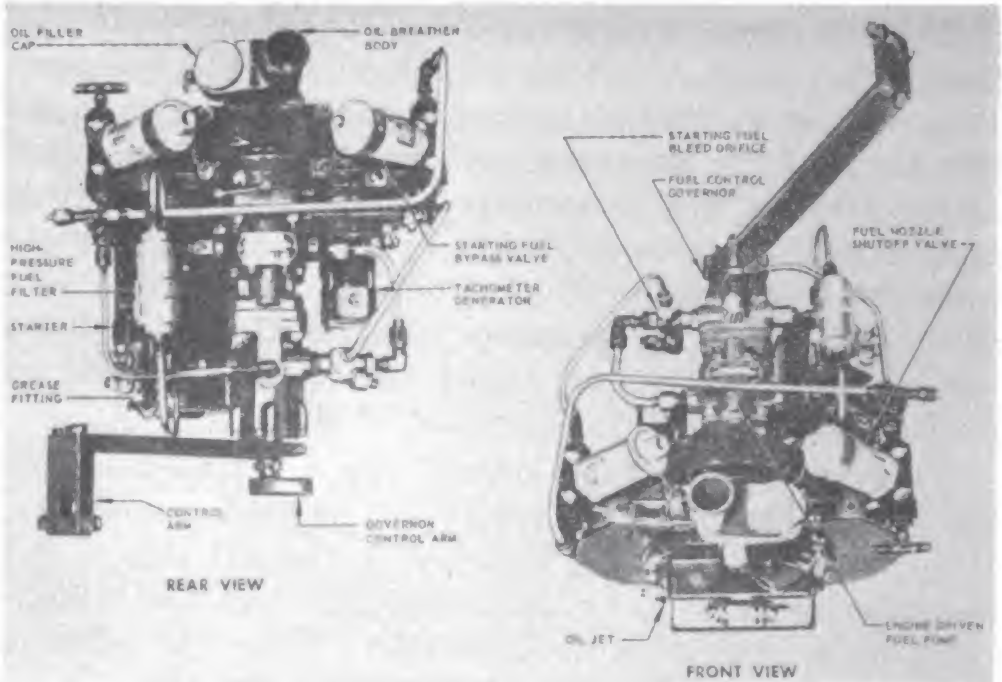


Figure 10–6.—Accessory-drive unit and accessories.

internal pressure relief valve. The two sections of the filter housing are screwed together and sealed by an O-ring. The pressure relief valve is generally set to open at a differential pressure ranging from 26 to 31 psi.

PUMPS.—A motor-driven vane type pump (the fuel supply pump) transfers the fuel from the supply tank to the fuel inlet of each engine. As viewed from the pump end of the assembly, the pump rotation is counterclockwise, and at 2000 rpm capacity is 100 to 200 gallons per hour. The pressure range of the pump is adjustable from 2 to 20 psi; however, the desired operating pressure is 15 psi. Seal leakage drain ports are located directly behind the pump body. When viewed from the pump end of the assembly, the fuel inlet port is on the left and the fuel outlet port is on the right.

A gear type fuel pump, mounted on the center pad of the accessory-drive unit (fig. 10–6), is driven at a speed ratio of 1 to 12 of the rotor. The fuel governor is attached to the end of the pump body, with the pump and

governor shafts connected together for common drive. The engine-driven pump receives fuel from the supply pump, and forces it through the high-pressure filter to the governor.

NOZZLES.—Each nozzle assembly, consisting of a 115-mesh screen, an insert, and a head, is screwed into an adapter. The latter is threaded into a supporting horn cast in the center rear of the burner elbow. A drilled passage in the elbow conducts the fuel from the nozzle shutoff valve line to the nozzle. Fuel enters the nozzle through the strainer screen and passes through grooves in the insert to the head, where it is discharged through the orifice in the nozzle tip. Each nozzle is flow-rated at 9.5 gallons per hour, at 100 psi, for use with Diesel oil.

GOVERNOR.—The fuel governor, shown in figure 10–7, is a centrifugal flyweight type governor that controls the engine speed by metering the flow of fuel to the nozzles. The governor is mounted on the end of the engine-driven fuel pump, and its drive sleeve (shaft) is directly connected to the pump shaft and rotates at the same speed.

The drive sleeve, to which the flyweights are attached (fig. 10–7), serves as a rotating bushing around the pilot valve plunger. As the flyweights rotate, their centrifugal force is opposed and balanced by the speeder spring. The compression of a speeder spring can be adjusted by moving the control arm. (The range of movement of the control arm is limited by a stop ring with high-speed and low-speed adjusting screws.)

By referring to figure 10–7, you will notice that the governor has 3 ports: (1) an inlet port connected to the high-pressure side of the engine-driven pump, (2) an outlet (metered flow) port connected to the line supplying the fuel nozzles, and (3) a return (low pressure) port through which excess fuel is returned to the low-pressure side of the pump.

The differential pressure relief valve provides a pressure drop of 40 to 60 psi across the metering port. In

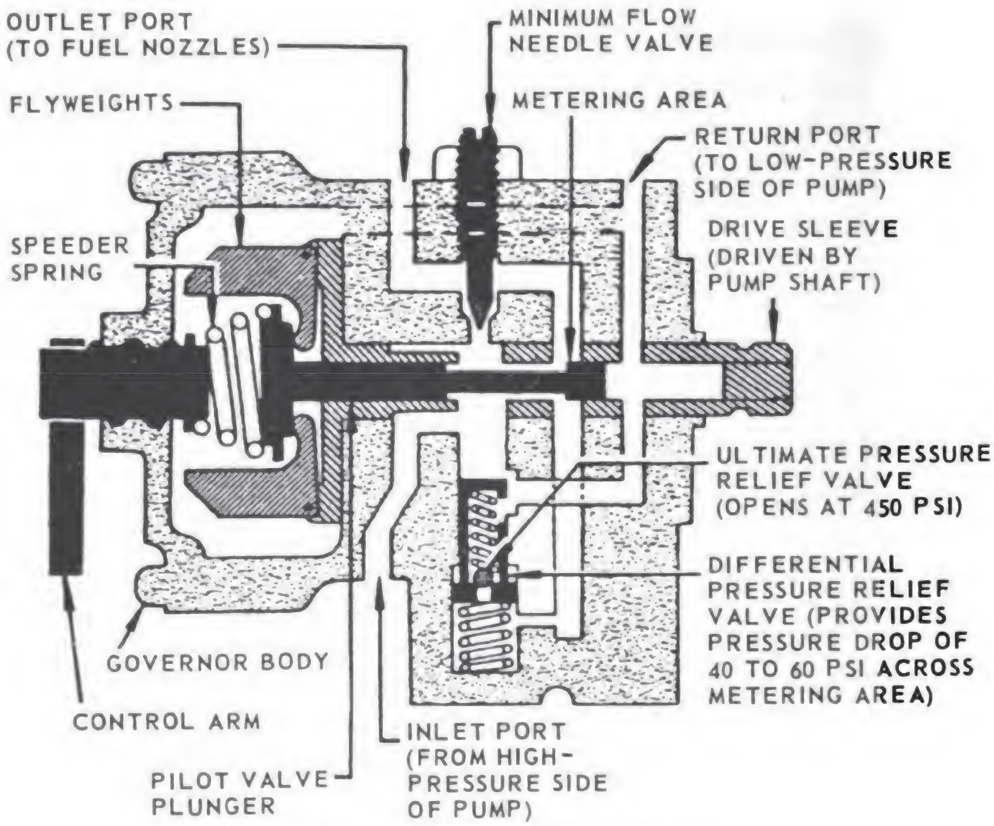


Figure 10–7.—Fuel control governor.

addition to the force exerted by the valve spring, this valve is backed up by the governor discharge pressure. The ultimate pressure relief valve, in the differential valve plunger, opens when the governor discharge pressure exceeds approximately 450 psi. When the metering port is closed, the minimum flow needle is preadjusted to provide sufficient fuel flow to the nozzles in order to maintain combustion.

The governor is in equilibrium when (1) the engine is operating at a constant speed, (2) the centrifugal force of the flyweights is balanced by the force of the speeder spring, and (3) the pilot valve is positioned to pass the amount of fuel required to maintain engine speed. Excess fuel is returned to the input side of the engine-driven pump by the differential relief valve.

Any increase in engine speed above the governor speed setting will cause the centrifugal force of the flyweights

to overcome the speeder spring tension. This, in turn, causes the control arm to move the pilot valve plunger so as to decrease the flow through the metering ports. Thus, the fuel flow to the nozzles is decreased, returning the engine speed to its former rate.

If the engine speed decreases, the flyweight force diminishes and the speeder spring moves the pilot valve plunger to increase the flow through the metering ports. This results not only in an increase in nozzle pressure but also in a corresponding increase in engine speed.

As the throttle is advanced or retarded, the governor control arm is repositioned to change the compression of the speeder spring accordingly. When governor equilibrium is again established, fuel is metered to the nozzles, as required, to produce an engine speed which corresponds with the throttle position.

ENGINE OIL SYSTEM

Lubrication within gas turbine engines is provided by a circulative type engine oil system. In addition to the lines and strainers, the major components of the engine oil system are an oil thermoswitch, a combination pressure-scavenge pump, a manifold, and a pressure switch. An external oil cooler and filter are incorporated in the system between the pressure outlet port of the pump and the inlet port of the oil manifold.

Oil from the supply reservoir (one gallon capacity), located in the forward end of the engine base, flows to the pressure section of the oil pump. At normal operating speeds, the pump circulates the oil (at 35 to 70 psi) through the cooler and filter to the manifold. From the manifold, the oil is distributed to the accessory-drive unit, rotor housing, and engine reduction gear. The line to the accessory-drive unit is connected to an oil jet which provides spray lubrication for all accessory-drive gears and bearings. Oil is supplied to the rotor bearings through internal passages in their respective housings. Lubrication of the rotor and the engine reduction is shown

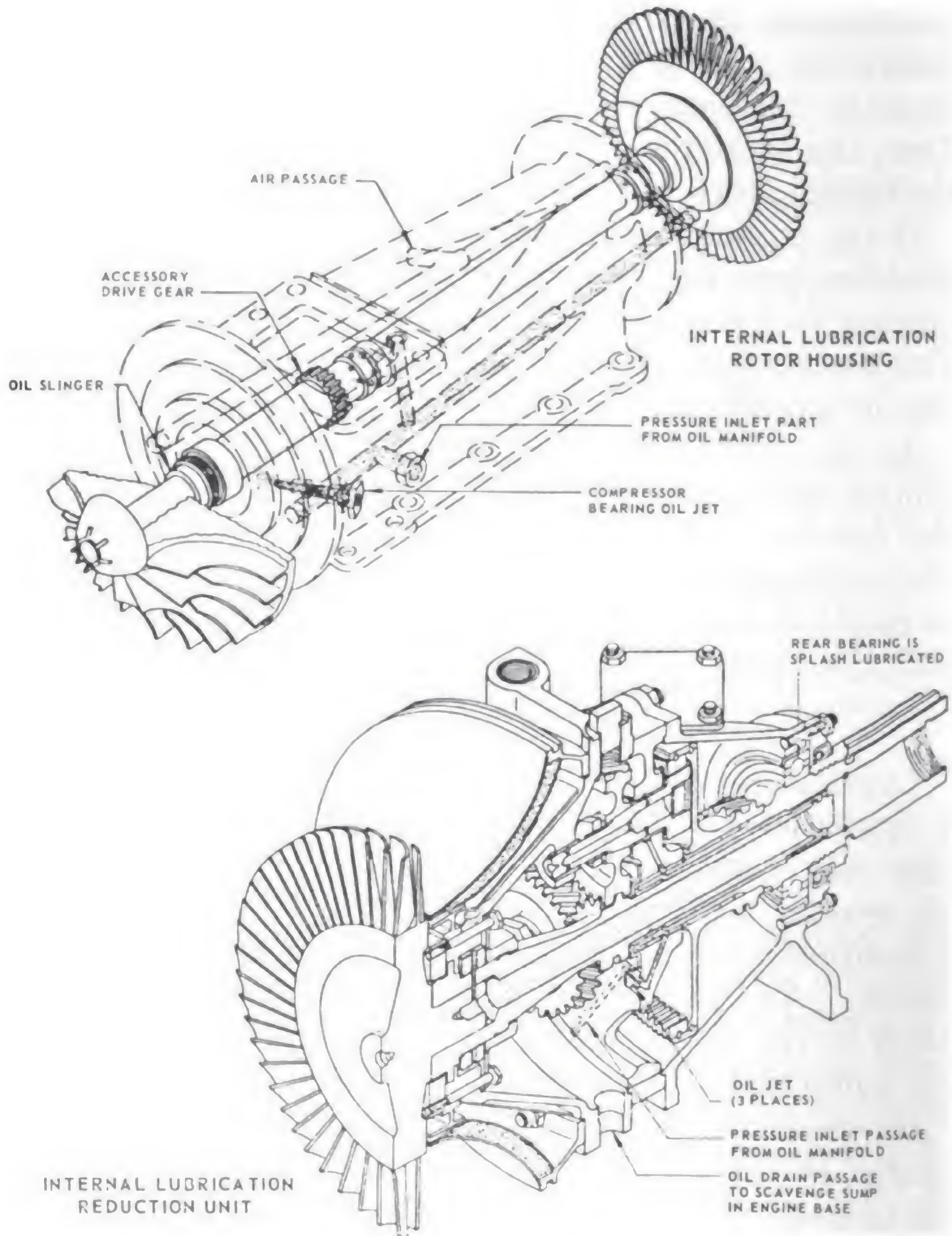


Figure 10–8.—Internal lubrication of rotor housing and engine reduction unit.

in figure 10–8. Oil supplied to the rotor bearings and the accessory-drive unit returns to the supply reservoir by gravity. Oil supplied to the reduction unit drains into a separate sump. The scavenge section of the pump returns oil from the sump to the rotor housing. From there it drains into the supply reservoir.

Combining Reduction Gear Oil System

The major components of the combining gear oil system are a pressure pump, filter, oil galleries and spray nozzles in the gear case, scavenge pump, breather, and associated tubing. The oil is cooled by being circulated through an external cooler. An oil pressure gage and high oil-temperature warning light are on the engine control panel.

The rotating elements and bearings of the combining gear, and the single bearing of the generator are lubricated by a separate oil system which also provides fluid for hydraulically actuating the generator speed control system.

Oil identical to that used for the engines is supplied from a sump which forms the bottom of the gear case. (The sump has a capacity of 8 gallons and can be drained by removing the cap on the outlet tee.)

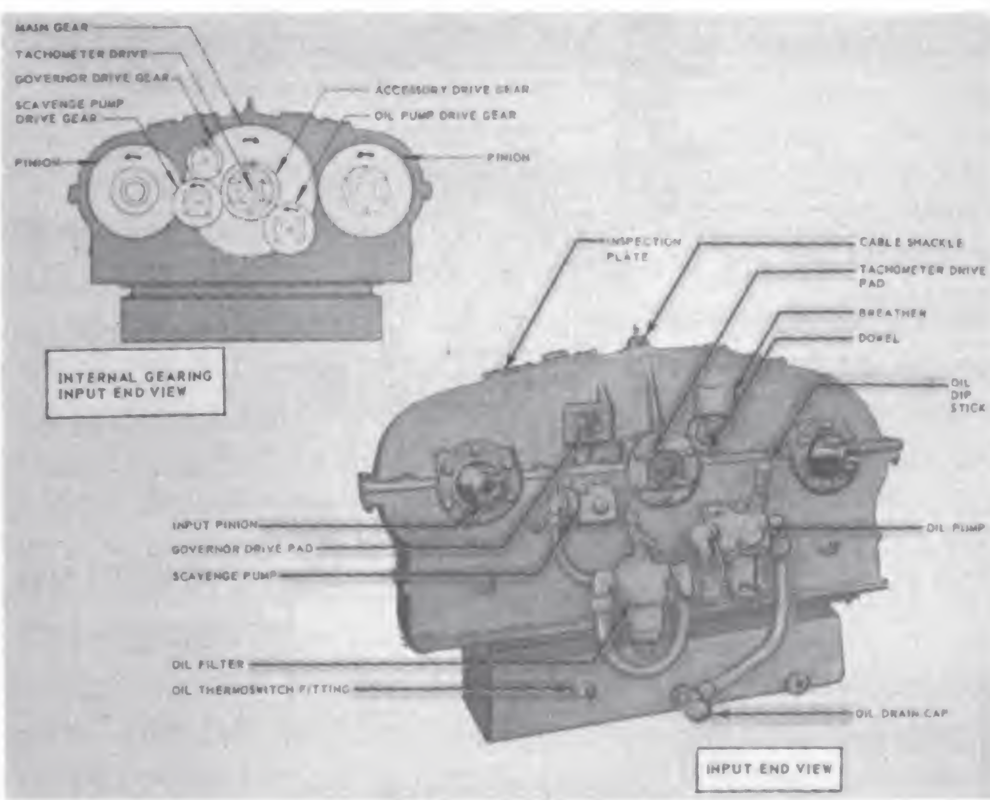


Figure 10–9.—Input end views of combining reduction gear.

Oil drawn from the sump flows through a tee fitting and tubing to the oil pump. At normal operating speed, the pump circulates oil at 12 to 15 psi, through the oil cooler and oil filter, to an inlet fitting directly below the tachometer drive. Inside the gear case, galleries and riser passages drilled in the housing conduct the oil to the bearings on the pinion, main, and accessory gear shafts, and to the spray nozzles. Figures 10–9 and 10–10 illustrate sectional views of the combining reduction gear.

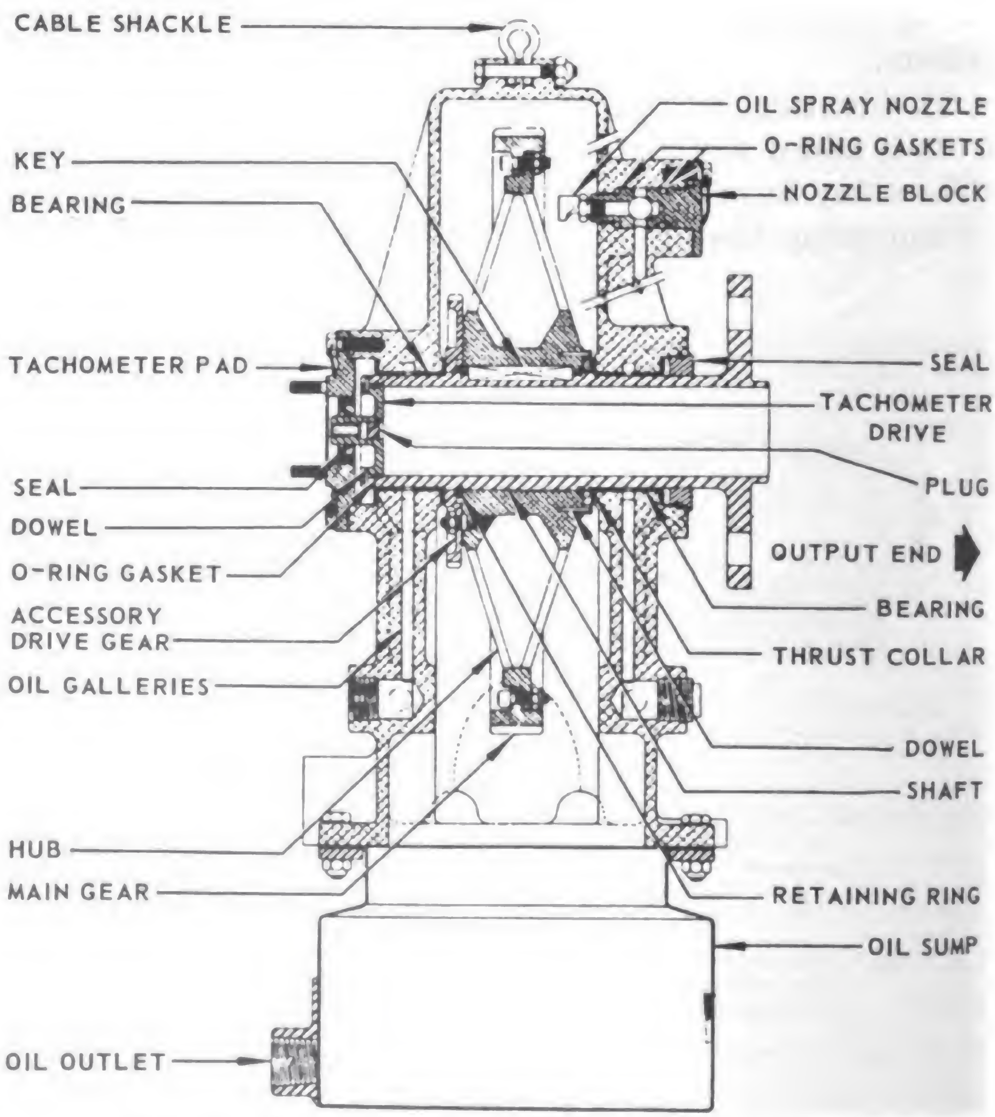


Figure 10–10.—Sectional view through main gear and shaft.

The combining gear oil-pressure indicator is connected to a fitting on the output end of the gear housing, and registers the gallery oil pressure. A thermoswitch threaded into the input end of the gear sump actuates the combining gear oil temperature warning light when the oil temperature exceeds 180° F.

Oil which lubricates the combining gears and bearings returns to the supply sump by gravity. A separate pump scavenges the oil which lubricates the generator bearing and discharges it, through an open tube, into the gear sump. Oil removed from the galleries and used in the generator speed control system is returned to the galleries, as permitted, by a separate relief valve.

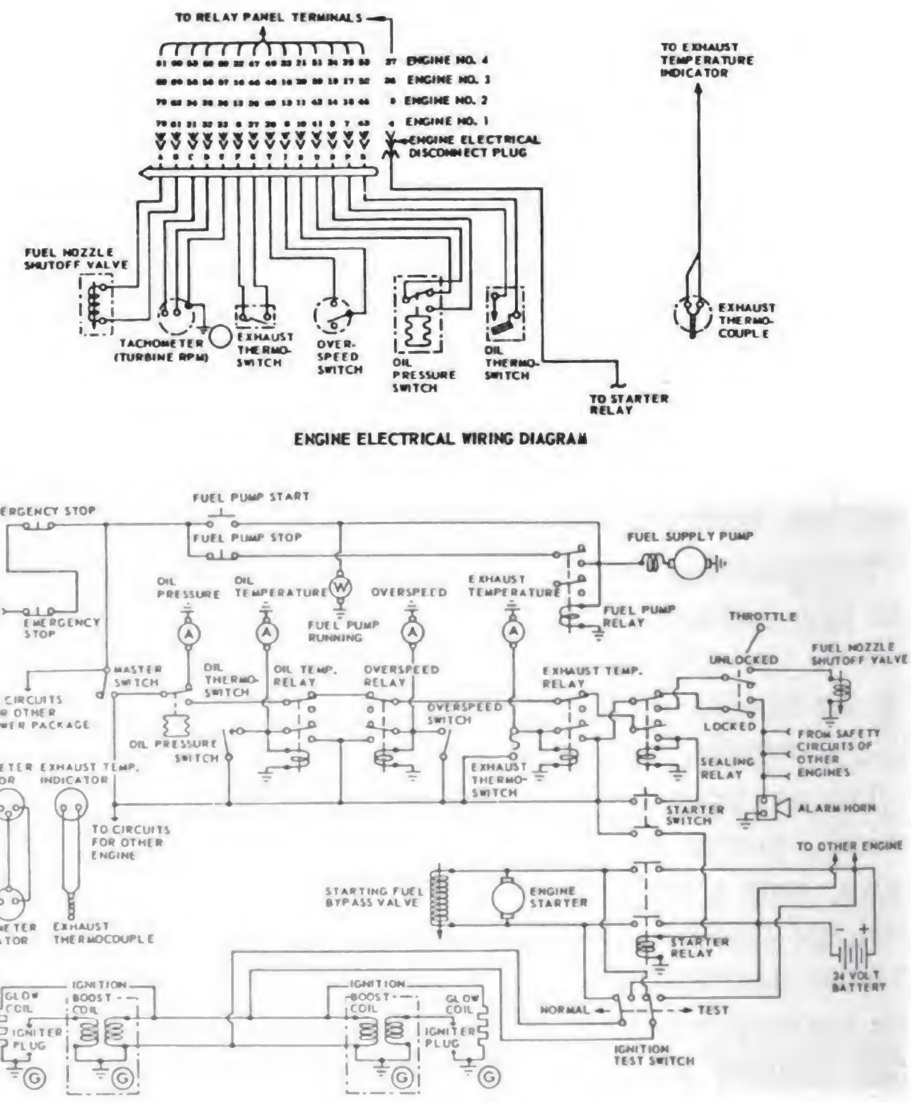
Electrical Systems and Equipment

The electrical system starts the engines, operates certain instruments and warning devices, and automatically stops the engine if the operating limits are exceeded. The system consists of the following circuits: starting, ignition, indicating, warning, and safety circuits.

The starting and ignition circuits receive power from storage batteries, and the warning and safety circuits receive power from the ship's power supply panel. Power for the indicating circuit is self-generated by parts (for example, the thermocouple) in the circuits.

The STARTING CIRCUIT for each engine includes a starter switch, power relay, starter motor, starting fuel-bypass valve, and a fuel nozzle shutoff valve. With the power package master switch ON and the throttles locked in the CLOSED position, each engine can be started by pressing the corresponding starter push-button switch on the engine control panel. The starter relay is energized and the relay operation completes the power circuit from the battery to the starter motor, the starting fuel-bypass valve, and the ignition circuit. When a cranking speed of approximately 5000 rpm is reached and the throttle is pulled outward (unlocked), an additional circuit is com-

pleted through the sealing relay (fig. 10–11), the throttle-actuated microswitch, and the fuel nozzle shutoff valve, opening the fuel line to the nozzles. When the starter switch is released, the ignition circuit, the starter relay, and the starting fuel-bypass valve are deenergized. The fuel nozzle shutoff valve remains energized through



NOTES

GROUND SYMBOLS INDICATE A COMMON RETURN WIRE EXCEPT POINTS Ⓖ WHICH ARE ACTUALLY GROUNDED TO TURBINE.
CIRCUITS SHOWN WITH ENGINE NOT RUNNING.

Figure 10–11.—Schematic view of engine electrical system.

the safety circuit until the engine is stopped either manually or automatically.

Two 200-ampere intermittent duty starting relays, mounted on a bracket at the top of the compressor case, connect the batteries to the starters of both engines. When the master switch and the starter switch are in their respective ON positions, the coil of the starter relay is energized to close the relay contacts and complete the power circuit from the batteries to the engine starter, the starting fuel-bypass valve, and the ignition circuit.

The engine starter is mounted on the lower left pad on the rear side of the accessory-drive unit. It is mechanically connected to the rotor shaft through the accessory gearing, and electrically connected, through the starter relay, to the batteries. The starter, which has been modified recently, consists of a sealed-type starter end bearing and a heat shield between the starter and the nozzle box.

The starting fuel-bypass valve, mounted on a bracket attached to the right side of the accessory-drive unit, is identical to the fuel nozzle shutoff valve. Spring-loaded and closed, the bypass valve is installed between the engine fuel inlet and the fuel nozzle shutoff valve. Electrically, the bypass valve is connected in parallel with the engine starter; both units are energized simultaneously by battery power. In conjunction with the starting fuel-bleed orifice, the bypass valve limits the pressure in the fuel lines to prevent flooding of the combustion chambers, during engine starting.

The IGNITION CIRCUIT for each engine, consisting of an ignition test switch, two ignition boost coils, and two glow type igniter plugs, is energized at the same time as the starting circuit. After initial starting develops steady combustion, engine operation is self-sustaining. The ignition circuit is de-energized when the starter push button is released. The ignition circuit can be isolated to check the operation of the boost coils and the igniter

plugs periodically by holding the ignition test switch in the TEST position.

Two ignition boost coils, as shown in figure 10–11, are attached to a bracket at the lower front of the compressor case. (These coils provide a high-voltage impulse to the igniter plugs.) The primary (low-voltage) circuit of each coil is connected to the battery through the ignition test switches. The secondary (high-voltage) circuit is connected, by means of a high-tension ignition lead, to the igniter plug. One end of the secondary winding is grounded to provide a circuit for the ground electrode of the igniter plug. At normal system voltage, the boost coil relay is adjusted to allow a current flow of 1.2 amperes.

An igniter plug, installed on a boss in the lower side of each burner elbow, projects through the wall of the burner liner and into the combustion chamber. Each igniter plug has two electrodes and a glow coil which is a resistance heating unit that vaporizes the fuel-air mixture in the electrode area. Electrode spacing of .070 and .080 inch is required, and the igniter plug gasket should be replaced every time the plug is removed. During the starting cycle, the primary circuit to the ignition boost coil and the glow coil is energized. In addition, the high voltage from the ignition boost coil is supplied to the center electrode. The outer electrode is grounded to the igniter plug shell.

A chromel-alumel EXHAUST THERMOCOUPLE, threaded into a fitting in the inboard side of the exhaust collector, measures the temperature of each engine exhaust. The temperature is registered on an exhaust-temperature indicator (millivoltmeter) on the control panel. Since the voltage developed at the thermocouple is related to temperature, calibrated leads and a resistance unit in series with the negative lead are used to match the thermocouple and its indicator. Since the thermocouple is self-generating, its circuit is not connected to the electrical system or routed through the engine electrical coupling.

Disconnection must be made either at the terminal studs on the indicator case or at the coupling lugs of the thermocouple. The thermocouple leads must not be shortened or spliced without resistance compensation. The circuit resistance should be 8 ohms, and the normal gas temperatures at the exhaust collector should NOT exceed 1225° F (663° C).

A TACHOMETER GENERATOR, for each engine, is connected to dual gages on the control panel to indicate engine (rotor) speed. The rotor (first-stage turbine) speed is registered electrically from the proportional voltage developed by a two-pole a-c tachometer generator driven by the accessory gearing. The tachometer generator is bolted to an adapter plate secured to the lower right pad of the accessory-drive unit. A short coupling adapts the square drive of the tachometer generator to the drive gear splines.

The WARNING CIRCUIT consists of indicating lights and an alarm horn. Except for one, all the indicating lights are actuated by engine safety circuit components, and the alarm horn can be actuated by the safety circuit whenever the throttle is unlocked.

A white light on the engine control panel indicates the operation of the fuel supply pump. Four amber warning lights are provided for each engine, in order to indicate the cause of automatic shutdown.

The low oil-pressure warning light, operated by the pressure switch at the engine oil manifold, turns on simultaneously with the master switch. When the oil pressure rises above minimum, the light will turn off until either normal or automatic shutdown of the engine. Thus, if automatic shutdown occurs for any reason other than low oil pressure, this light and the one indicating the cause for shutdown will be burning (on).

The other three warning lights for each engine indicate high oil temperature, engine overspeed, and high exhaust temperature. As shown in figure 10–11, the high oil temperature light is operated by the oil thermoswitch in

the oil supply strainer, the overspeed light by the overspeed switch on the engine reduction unit, and the high exhaust temperature light by the exhaust thermoswitch in the exhaust collector. These lights can be turned off by the master switch, which will reset the actuated safety circuit relay for future actuation.

If a throttle is unlocked prior to engine cranking, or automatic shutdown occurs at any time the engine is started, the alarm horn behind the engine control panel will sound until the throttle is returned to its locked position (pushed inward) or the master switch is turned off.

A SAFETY CIRCUIT, provided for each engine, consists of a pressure switch, speed and temperature actuated switches, and associated relays. If low oil pressure, high oil temperature, overspeed of engine, or high exhaust temperature results after the engine is started, the safety circuit will automatically stop the engine.

By referring to figure 10–11, you will notice that the activation of the following units will result in opening a series circuit to the sealing relay: the oil pressure switch, oil thermoswitch and oil temperature relay, overspeed switch and overspeed relay, and exhaust thermoswitch and exhaust temperature relay.

Initially, the engine starter switches close the sealing relay (this unit and the throttle microswitch control the fuel nozzle shutoff valve circuit). When the engine cranking speed reaches approximately 5000 rpm and the throttle is unlocked (pulled outward), a circuit is completed, through the sealing relay and throttle microswitch, to open the fuel nozzle shutoff valve to permit the flow of fuel to the burners.

During engine cranking, the oil pressure increases and the oil pressure switch transfers power from the oil pressure warning light supply to a circuit through the contacts of the oil temperature relay, overspeed relay, exhaust temperature relay, and sealing relay. In this way, a safety circuit is established to keep the coil of the seal-

ing relay energized, and the fuel nozzle shutoff valve open, after the starter switch is released.

The sealing relay is de-energized either by locking the throttle or turning off the master switch. In addition, the relay is de-energized when pressure, speed, or temperature conditions open the safety circuit which results in automatic shutdown. If automatic shutdown results from excessive speed or temperature, the master switch must be turned off so that the actuated relay is reset and continuity of the circuit restored. (The actuated relay is self-holding after initial closure.) If low oil pressure causes automatic shutdown of the engine and you want to restart the engine, it will not be necessary to turn the master switch off.

The ENGINE SWITCHES which you should be familiar with are the ENGINE OIL PRESSURE SWITCH, the ENGINE OIL THERMOSWITCH, the ENGINE OVERSPEED SWITCH, and the ENGINE EXHAUST THERMOSWITCH. The functions of these switches are explained in the following paragraphs.

When the master switch is ON and the engine oil pressure is below minimum (18 to 20 psi), a diaphragm type pressure switch connected to the engine oil manifold turns on an amber warning light. At pressures above 20 psi, the warning light is off and the switch completes (with other relays) the safety circuit to the sealing relay.

A thermoswitch unit, consisting of a tubular capillary and bellows assembly which operates a snap-action switch through an adjustable spring-loaded arm, is threaded into the oil supply strainer mounting plate on the left side of the engine. When the engine oil temperature exceeds 265° F, the engine oil thermoswitch closes and energizes a relay which opens the safety circuit. As a result, the engine is automatically stopped and an amber warning light turns on to indicate the cause of the shutdown.

The engine overspeed switch shuts down the engine automatically and warns personnel if the engine overspeeds. Centrifugal flyweights, driven by the engine

reduction gear at ½ output shaft speed, trip the overspeed switch at a preset limit. At approximately 2300 generator shaft rpm, the flyweights deflect sufficiently to close the switch, turning on an amber warning light, and energizing a relay which opens the safety circuit to stop the engine automatically. After any overspeed trip, the switch must be manually reset by depressing the button at the center of the switch housing.

The engine exhaust thermoswitch, threaded into a fitting in the outboard side of the exhaust collector, closes when the gas temperature (at the exhaust collector) exceeds 1300° F. When the switch contacts close, the relay is energized and opens the safety circuit to stop the engine automatically. In addition, an amber light turns on to indicate the cause of the shutdown.

Switches, instruments, and warning lights for remote operation of the gas turbine engines of two power packages are on a control panel, as shown in figure 10–12. For simple identification purposes, these units are arranged in vertical groups for each engine, with each half

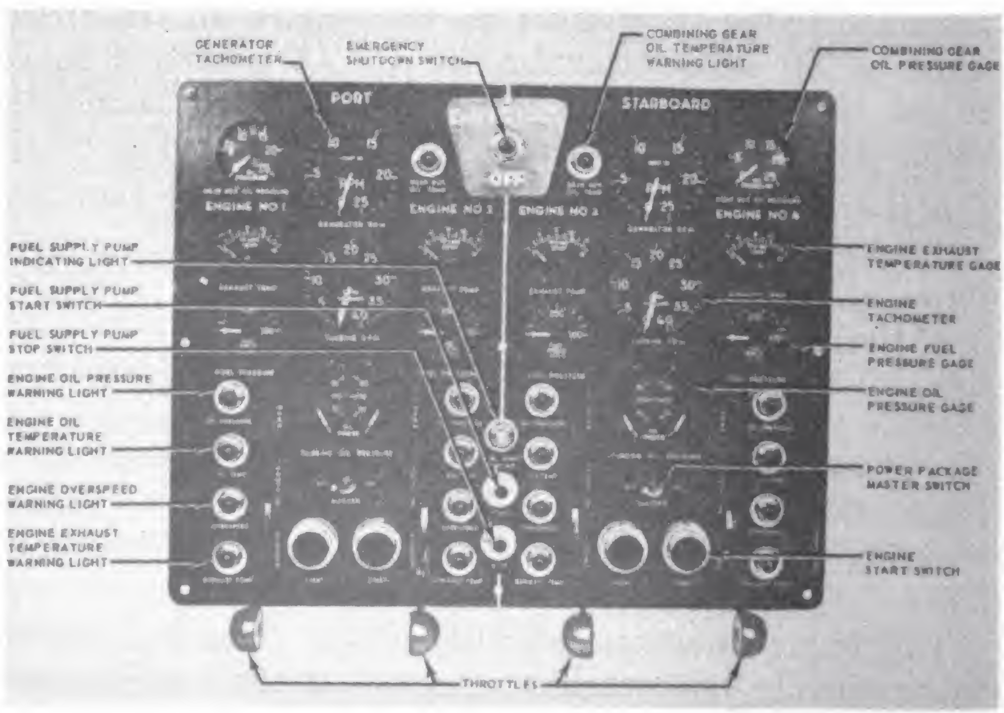


Figure 10–12.—Engine control panel.

of the panel containing the necessary equipment for operational control of one power package.

The wires between the switches and the warning lights on the control panel and the relays on the relay panel are routed through disconnect plugs at the rear of the control panel. All other wiring, except thermocouple leads, for the power package electrical circuits is connected to the relay panel terminal strips. Each of the tachometers on the control panel (two single gages indicating generator speed and two dual gages indicating engine turbine speeds) have individual disconnect plugs.

Generator Speed Control System

During generator operation, the gas producing section of each engine is operated at approximately maximum speed, to provide a sufficient flow of combustion gases to the power-output section of the engine. At intermediate generator loads, the gas flow divides after it leaves the first-stage turbine; only the flow necessary for the required power output passes through the second-stage turbine and exhaust collector. Excess gas is bled into the exhaust system ahead of the second-stage turbine through an interstage bleed duct. The amount of bleed is regulated by gate type valves in the interstage bleed and the turbine exhaust ducts of each engine. The valve gates are identified as the waste gate in the interstage bleed duct and the exhaust damper in the turbine exhaust duct. At maximum generator load, the exhaust damper is wide open and the waste gate is closed. Under no-load conditions, or zero generator output, the waste gate is wide open and the exhaust damper is closed sufficiently to maintain the rpm of the generator within the desired speed range. These valve gates, as shown in figure 10–13, are hydraulically positioned by a separate system consisting of a pump, a relief valve, a governor, an actuator, and mechanical linkage (from the piston rod to the valve gates and governor spring control arm.)

Before discussing the components of the speed control

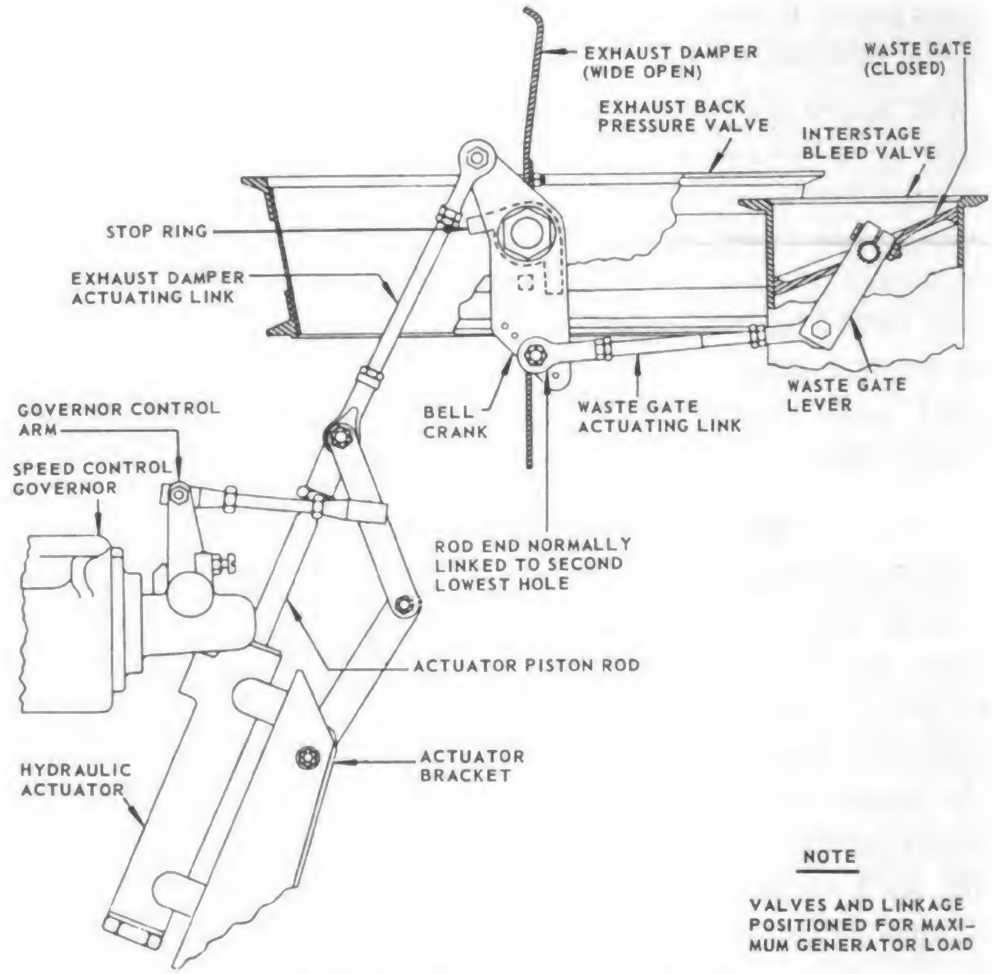


Figure 10–13.—Speed control system linkage.

system, the following information will serve to give you a better understanding of the operation of the system.

With reference to the hydraulic actuator, shown in figure 10–14, the speed control system pump supplies the upper end (chamber A) of the actuator cylinder with oil, through an inlet port near the top of the cylinder, at an approximate pressure of 450 psi. Oil is supplied to the lower end (chamber B) of the cylinder at governor-controlled pressure, through an O-ring sealed reducer bushing threaded into the bottom of the cylinder. With the area of the lower surface (C) of the piston twice that of the upper surface (D), piston equilibrium is established when the governor-controlled pressure is ½ that of the pump pressure.

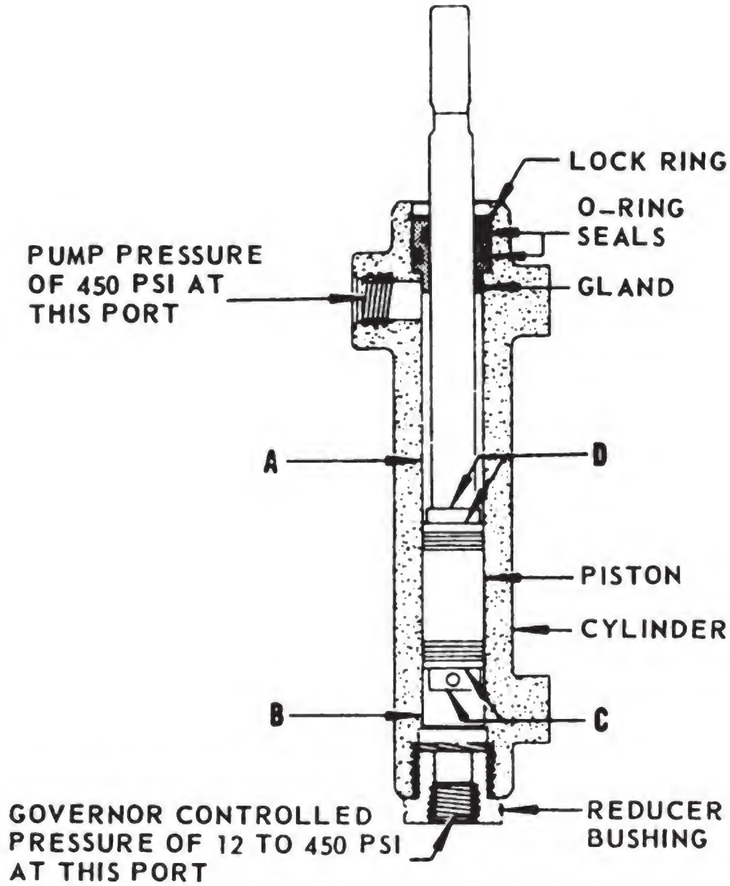


Figure 10–14.—Hydraulic actuator.

When the centrifugal force of the governor flyweights is balanced by the tension of the speeder spring (fig. 10–15), the pilot valve of the speed control governor blocks the outlet port, thus equalizing the hydraulic forces acting on each end of the actuator piston. Under this condition, the waste gates and the exhaust dampers are positioned to pass sufficient gas flow, through the second-stage turbine of each engine, to maintain a constant output speed, and the speed control system is in equilibrium.

When the generator load is decreased, an increase in speed occurs. The centrifugal force of the governor flyweights compresses the speeder spring and shifts the pilot valve. The governor outlet port is thus opened, through the return passage in the governor shaft bore, to the inlet side of the pump. In this way, the metered

pressure on the lower side of the actuator piston is decreased. Forced downward, the piston moves the mechanical linkage which increases the governor speed setting and simultaneously opens the waste gates and closes the exhaust dampers of both engines. This action dumps sufficient gas flow through the interstage bleed ducts in order to maintain constant speed of the second-stage turbine wheel of each engine. Thus, equilibrium is reestablished.

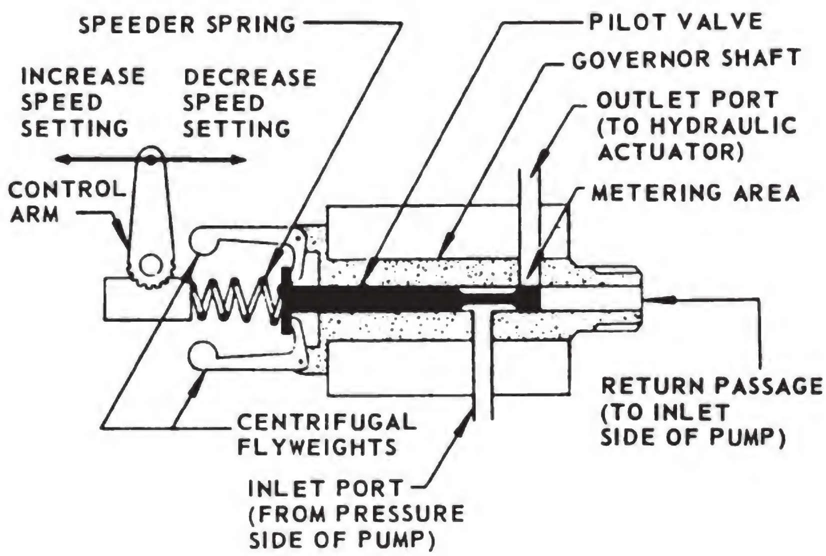


Figure 10–15.—Speed control governor.

Conversely, an increase in the generator load results in a decrease in rpm and flyweight centrifugal force. This, in turn, results in speeder spring expansion, shifting the pilot valve in the opposite direction. The governor inlet and the outlet ports are then interconnected to apply pump discharge pressure to the lower surface of the actuator piston. The piston reacts by moving upward, causing the linkage to reverse the position of the waste gates and the exhaust dampers, and to decrease the governor speed setting, as required, to again restore equilibrium.

SPEED CONTROL SYSTEM PUMP.—A gear type pressure pump, mounted on a drive pad on the input end of the combining gear upper housing, is driven at a ratio of 1.5

to 1 of the generator. The pump receives oil from the combining gear pressure galleries and transmits it to the inlet port of the governor and to the upper end of the actuator cylinder at an approximate system pressure of 450 psi.

PRESSURE RELIEF VALVE.—An adjustable relief valve, attached to a bracket bolted on one of the inspection plates of the combining gear upper housing, limits the system pressure. The inlet port of the valve is connected to the pressure line between the pump and the governor. At a pressure above 450 psi, the discharge port of the valve opens and the oil is returned to the combining gear pressure galleries.

SPEED CONTROL GOVERNOR.—This unit is attached to the end of the pump body mounted on a drive pad on the input end of the combining gear upper housing. The governor and pump shafts are connected together and driven at the same speed. As shown in figure 10–15, the governor inlet port receives oil under pressure from the pump, and the governor outlet port is connected to the lower end of the actuator cylinder. A separate passage (return) in the governor shaft bore allows oil to be returned to the inlet side of the pump. An adjustable rod connects the governor control arm to the mechanical linkage operated by the actuator piston. The centrifugal flyweights, opposed by a speeder spring, control the position of a pilot valve in relation to the governor metering port. The position of the flyweights and the pilot valve is determined by the governor speed and the spring tension. (The spring tension is regulated by the position of the control arm.)

The speed control governor is of the droop or proportional control type; the governed speed of the generator is higher under no-load conditions than at full load. (Droop is defined as the variation in speed setting expressed in percent of the average speed.) The governor is adjusted to a 7 percent droop that maintains a no-load

generator speed 7 percent greater than the full-load speed (approximately 2100 rpm and 1950 rpm respectively).

HYDRAULIC ACTUATOR.—This unit consists of an aluminum-bronze cylinder and a chromium-plated aluminum bronze piston. The piston rod, which is integral with the piston, extends through a lock-ringed aluminum-bronze gland at the top of the cylinder, with an O-ring providing a leakage seal. A brass reducer bushing is threaded into a tee member of the speed control system linkage so that the movement of the piston will operate the governor control arm, and the waste gates as well as the exhaust dampers of both engines.

EXHAUST BACK-PRESSURE VALVE.—The flow of combustion gases through the second-stage turbine is controlled by the exhaust back-pressure valve. The valve assembly, clamped between the exhaust collector and the turbine exhaust duct, consists of a circular gate (damper) welded to a shaft that is supported by bosses in the valve body. (The shaft has Stellite bearing surfaces.) Damper travel is limited by a stop lug welded to the valve body and a brass stop ring keyed to the damper shaft. Actuated links of the exhaust damper and waste gate are connected to a bell crank on the shaft extension. (All parts of the valve assembly except the stop ring are of stainless steel.)

INTERSTAGE BLEED VALVE ASSEMBLY.—Gas flow in excess of the amount required in maintaining constant second-stage turbine (and generator) speed is dumped through the interstage bleed valve assembly. The latter is clamped between the bleed outlet of the interstage bleed nozzle duct assembly and the interstage bleed duct. The valve assembly is a 45° stainless steel elbow enclosing an elliptically shaped waste gate. The gate is permanently mounted on a shaft supported by bosses in the valve body, and the waste gate travels from closed to wide open, through a 70° arc. A lever, splined and bolted to the shaft extension, is linked to the exhaust back-pressure

valve bell crank to provide synchronous movement of the waste gate and exhaust damper.

At maximum load, the waste gate is closed completely, forcing all of the gas flow through the second-stage turbine. Without generator load, the waste gate is wide open and the exhaust damper closed sufficiently to maintain the rpm of the generator within the desired speed range.

OPERATION OF GAS TURBINE ENGINES

Prior to starting the engines, the following steps should be taken:

1. Remove protective covers (if installed) from the exhaust stack outlets.
2. Remove the inside panel of the shroud on the port and starboard sides and the outboard port shroud. Check the level of the engine oil and, if necessary, add oil to "FULL" mark on the dip stick. Do not overfill.
3. Drain condensation from the fuel filter drain valve.
4. Close the engine exhaust collector condensation drain valves.
5. Inspect the power package and related systems for fuel or oil leakage, and other fire hazards.
6. Turn the flexible coupling counter to the direction of the drive, and check the ease of rotation of the second-stage turbine wheel and the reduction unit gearing. At the same time, turn the brass outer race clockwise, as viewed by the engine, and check the clutch for overrun. (Partial or temporary locking of the clutch may occur and can be overcome by inserting a bar between the engine output shaft and the compression bolts of the flexible coupling, and prying in the overrun direction.)
7. Check the level of the combining gear oil supply. Add oil to "FULL" mark on the dip stick.
8. Turn the ratchet handle on top of the combining gear oil filter clockwise two full turns.

9. Check for oil leakage at the forward end of the main generator bearing.
10. See that the exhaust dampers are wide open by having the servo actuator piston rod full out.

Starting the Engines

The NORMAL STARTING procedure used to start gas turbine engines is as follows:

1. Press the "START" switch of the fuel supply pump. (The fuel pump running indicator light should turn on, indicating that fuel is being supplied to fuel inlets of all engines.)
2. Turn on both master switches. (The oil pressure warning lights should turn on for the generator set selected to be started first. The oil pressure lights for the other set should turn on after the output of the ship's service generator on the first set has reached 120 volts. The alarm horn will sound if any throttle is not locked in the "CLOSED" position, or pushed inward.)
3. Press and hold the engine "START" switch closed. (The starting fuel-bypass valve will open and the ignition circuit will be completed. As the cranking speed increases, the fuel pressure and the turbine lube oil pressure gages should indicate a rise in pressure. The oil pressure warning light should turn off when the engine oil pressure reaches approximately 20 psi.) To avoid overheating the starter and ignition boost coils, do not exceed any cranking periods beyond 30 seconds. It is advisable to allow 5-minute cooling periods between cranking cycles.
4. Observe the fuel pressure gage. If the pressure does not increase to at least 50 psi before the turbine speed reaches approximately 5000 rpm, release the "START" switch and determine the cause of the trouble. If the fuel pressure is greater than 150 psi during cranking, at 5000 rpm or less, do not

open the fuel valve. Release the starter switch and investigate the cause of high pressure. (The trouble may be a faulty bleed valve, too small an orifice in the bleed line, an obstruction in the line, or a faulty first-stage governor.)

5. Observe the turbine lube oil pressure gage. Oil pressure should begin to register and increase with turbine speed. However, if the instrument is lagging, the pressure increase may not be evident until idling speed is reached.
6. At 5000 turbine rpm, pull the throttle outward (unlock the throttle). This positions the throttle at the idle speed setting and opens the fuel nozzle shutoff valve, permitting fuel to flow to the burners. The engine should fire and accelerate, within 5 seconds, to approximately 15,000 rpm. (If the engine does not accelerate to 15,000 rpm within 5 seconds, an abnormal start has been encountered. In this case, push the throttle inward, continue to press the "START" switch for a few seconds in order to clear the combustion chambers and allow accumulated fuel to be discharged through the nozzle box drain line.)
7. If the oil pressure warning light is off when an idling speed of approximately 15,000 rpm is reached, release the "START" switch. (The starting and ignition circuits will be de-energized and the starting fuel-bypass valve will close. Engine operation should now be self-sustaining.)
8. If the oil pressure is increasing and the warning light remains on at idling speed, continue to hold the switch closed until the light goes off. If the "START" switch is released prematurely, the engine will shut down automatically because of a low oil pressure. However, if no oil pressure is indicated at idling speed, stop the engines and determine the cause of the trouble.

COLD WEATHER STARTING, at low ambient temperatures (10° to 0° F), may be difficult due to low cranking speed and insufficient vaporization of fuel. To provide easier starting under such conditions, engine frictional losses can be reduced by using a lighter lubricating oil of Specification MIL-0-2104. Fuel vaporization can be improved by using a low-temperature Diesel fuel of Specification MIL-F-16884.

The types (3) of ABNORMAL STARTING which may occur are as follows:

FALSE STARTING.—The engine will not start. Combustion fails to occur as a result of either fuel or ignition trouble. If lack of ignition is the cause, fuel will accumulate in the bottom of the burners and the nozzle box.

ONE BURNER STARTING.—The engine fails to accelerate from low-speed range because of insufficient fuel or ignition. Combustion may not exist in one burner due to lack of either fuel or ignition.

HOT STARTING.—The engine starts with a low rumbling noise due to (1) igniting fuel accumulated from a previous false or hot start; (2) igniting fuel accumulated from a leaking fuel nozzle shutoff valve; or (3) poor combustion resulting from carbon deposits either on the fuel nozzles or the burner liners. (All hot starts should be logged.)

Operating Limits

The limits tabulated on page 399 have been established for engine operation. If any of these limits are exceeded, the engine should be stopped, and the cause investigated and corrected.

Stopping the Engines

The NORMAL SHUTDOWN procedure for stopping the gas turbine engines is as follows:

1. Turn off the generator loads by pressing the STOP switch on the generator control panel.

Operating factors	Condition	Minimum	Normal	Maximum
Generator RPM	Rated load	1,860 rpm	1,920 rpm	....
	No load	....	2,120 rpm	2,140 rpm
	Auto. shutdown	....	....	2,300 rpm
Turbine RPM	Cranking	4,000 rpm	5,000 rpm	....
	Idling	15,000 rpm	....	....
	Rated speed	....	....	36,500 rpm
	Momentary	....	....	37,500 rpm
Turbine oil pressure	Rated speed	35 psi	50 psi	70 psi
	Auto. shutdown	20 psi	....	....
Fuel pressure	Starting	50 psi	100 psi	150 psi
	Rated speed	....	350 psi	500 psi
	Idling speed	....	10–50 psi	....
Exhaust temperature	Continuous	....	1150° F (621° C)	1225° F (663° C)
	Auto. shutdown	....	....	1300° F (704° C)
Gear box oil pressure	Rated speed	12 psi	15 psi	17 psi

2. Retard all four throttles to approximately 24,000 rpm. Then retard the two throttles to the generator set, not supplying 120-volt d-c power, to CLOSED position, but do not lock. Allow the engines to operate at idle speed (approximately 15,000 turbine rpm) for one minute. Then lock the throttles by pushing them inward.
3. Retard the throttles of the generator set still operating to the CLOSED position for one minute. Then lock the throttles by pushing them inward. (Combustion should cease immediately and exhaust temperatures should drop rapidly. The oil pressure of the engines will decrease, turning on the oil pressure warning lights. The engine rotors should stop in approximately one minute. These changes will occur for each generator set upon locking the throttles in step 2 and step 3. Retarding all four throttles to the closed position will cause the generator set, not supplying 120-volt d-c power, to be automatically shutdown due to the loss of voltage causing the interlock relay to open.)
4. Turn off the master switches.
5. Depress the fuel supply STOP switch. (The fuel supply pump running light will turn off.)

As far as the combining reduction gear is concerned, special instructions are not required in starting, operating, or stopping the combining gear because its rotating elements and accessories are driven directly by the engines. However, during engine operation, the gear oil pressure should be checked to ensure adequate internal lubrication of the gear system and the generator bearing. Excessive gear oil temperature will be indicated by a red warning light.

In an emergency, all engines can be stopped simultaneously by depressing either of the two EMERGENCY OFF switches. (One of the switches is on the engine control panel and the other is in the generator room.) Either

of these switches opens the circuits to the fuel supply pump and power package master switches. When one of the emergency switches is depressed, the fuel supply pump will stop, the fuel nozzle shutoff valves of all engines will close, and all warning and indicator lights will turn off.

If AUTOMATIC SHUTDOWN occurs on one engine, the other engine should be stopped by following the normal shutdown procedure. The cause of automatic shutdown is indicated by a warning light which will remain on until the master switch is turned off. (In event of a low engine oil pressure, only the low oil pressure warning light will be on. If automatic shutdown results from an excess speed or temperature, the corresponding warning light as well as the oil pressure warning light will be on.)

In addition to the engine warning lights, an amber warning light burns when the combining gear oil temperature rises above 180° F. If the gear oil temperature warning light is on, the engines of that power package should be stopped by following the normal shutdown procedure.

If the automatic shutdown occurs on the generator set started first and the other engine of that set is stopped, the generator set started last will also shut down automatically because the power relay to the cooling pumps will be interrupted due to the position of the 120-volt manual transfer switch.

Immediately after an automatic shutdown, you must check for free operation of the overrunning clutch on the dead engine. If the flexible coupling and outer brass cylinder of the overrunning clutch are not rotating, free wheeling is taking place. If the unit continues to rotate, the clutch is locked and the operating engine must be stopped immediately; otherwise the engine will drive the second-stage of the dead engine without benefit of lubrication. (Second-stage lubrication is provided by the first-stage oil pump, which would not be lubricated after an automatic shutdown.)

MAINTENANCE OF GAS TURBINE ENGINES

This section of the chapter contains adjustments and tests for gas turbine engines, as well as general maintenance procedures and precautions.

Adjustment of Engine Components

The following adjustments and tests may be accomplished, as required, at initial installation, after major overhaul, or during periodic maintenance.

THROTTLE CONTROL.—Moving the throttle from idle to full-speed position produces a corresponding movement of the governor control arm between the low-speed and the high-speed stops on the end of the governor housing. If the travel limits of the throttle and governor arm are not synchronized or throttle movement is partially restricted at either limit, inspect the throttle cable for binding and rubbing. In addition, check the cable support bracket and the governor control arm for proper position. Restricted throttle movement caused by interference between the governor control arm and the heat shield of the nozzle box can be corrected by bending the heat shield to obtain sufficient clearance. If the bolt clamping the cable support bracket around the end of the governor housing is not tightened securely, the bracket may shift; this results in the bending of the cable. However, excessive tightness of the clamping bolt may distort the governor housing. For ease of throttle operation, the governor control arm should be positioned on the serrations of the governor shaft so that it is perpendicular to the cable bracket when the throttle is centered on its range of travel.

If the inspection indicates that slack exists in the throttle cable, and the cable support bracket and governor control arm are properly positioned, it will be necessary to readjust the cable length. Disconnect the throttle cable rod at the governor control arm and rotate the rod

end in the proper direction. Reconnect the rod end to the governor control arm. The throttle cable clevis under the engine control panel permits similar adjustment if threading is insufficient in the rod end at the governor.

STARTING FUEL FLOW ADJUSTMENT.—During engine starting, fuel pressure is restricted at 50 to 150 psi, by an orifice in the starting fuel-bypass line. If difficulty is encountered with engine starting, particularly if any parts which affect fuel flow or pressure have been overhauled or replaced, check the starting fuel pressure. With the throttle depressed, in idle position, to close the fuel nozzle shutoff valve, crank the engine to a starting speed of 5000 rpm and observe the fuel pressure indicator. If the fuel pressure is lower than 50 psi, replace the existing orifice with the next smaller size. If the pressure exceeds 150 psi, install the next larger size to reduce the pressure to within the desired range. (Interchangeable orifices are made in .030, .035, and .040-inch sizes; a .035-inch orifice is generally installed. If the orifice is changed, the fuel pressure should be rechecked.)

ENGINE OIL PUMP.—The engine oil pressure-scavenge pump should deliver oil, through the engine oil cooler and filter, to the oil manifold at a pressure not less than 20 psi at idling speed or greater than 70 psi at maximum speed. (The normal operating pressure ranges from 35 to 70 psi.) The pump discharge pressure is limited by the compression of a spring acting against the poppet of an integral relief valve within the pump housing. If the normal engine oil pressure is not within these operational limits, the relief valve should be set to provide the proper pressure. Readjustment can be made with the engine at idling speed. (The engine oil pressure can be increased by turning the adjusting screw, on the left side of the oil pump, in a clockwise direction; turning the screw in a counterclockwise direction will decrease the pressure.)

ENGINE OIL THERMOSWITCH.—This switch is adjusted

to open the safety circuit to the sealing relay and to turn on an amber warning light whenever the engine oil temperature exceeds 265° F. When maladjustment of the thermoswitch is suspected, the unit should be removed from the oil supply reservoir strainer mounting plate and bench-checked. Remove the thermoswitch cover and attach a continuity light or ohmmeter across the switch terminals. Insert the tube of the thermoswitch into an oil bath heated to 265° (± 5°) F and allow several minutes for temperature stabilization. If the meter indicates a premature closing of the switch, turn the adjusting screw on the back of the thermoswitch to first open and then close the switch contacts at this temperature. A full turn changes the temperature setting approximately 4° F. This switch should be calibrated after it has been operated a total of 150 hours.

IGNITION BOOST COIL.—If the boost coil spark is weak, or there is no sound when the ignition test switch is held in the momentary TEST position, remove the coil from the engine and connect the primary terminal of the coil to a 24-volt d-c power supply. (An ammeter is generally connected in series with the power lead to indicate current flow through the coil.) Connect the secondary, or high voltage, lead of the boost coil to an igniter plug. Remove the screw plug at the primary lead end of the coil in order to get to the contact adjusting screw. With the power on, turn the adjusting screw to the position that allows the ammeter to indicate a current flow ranging from 1.0 to 1.2 amperes. If the current flow is below minimum, remove the screws that secure the case halves together and inspect the contact points. The surfaces of pitted points can be restored with a fine oil stone. When the inspection shows that most of the contact material has burned away, the points on the boost coil should be replaced. (To avoid damage to the ignition boost coil, remember that the igniter plug must be grounded to the coil body when the coil is tested on the bench. In addition,

the plug must be grounded to the engine when the coil is tested while installed on the engine.)

IGNITER PLUG.—When the spark gap of the igniter plug is suspected as the cause of faulty ignition during engine starting, disconnect the glow coil and the high-voltage wiring. Remove the igniter plug from the burner elbow. The electrode gap of the igniter plug should be .070 to .080 inch. If the wire feeler gage measurement shows that the spacing is not within these limits, the gap should be reset by bending the ground electrode only. Prying against the center electrode may crack the porcelain insulator. When the igniter plug is being reinstalled, the gasket should be replaced.

EXHAUST COLLECTOR THERMOSWITCH.—This unit is adjusted to open the safety circuit to the sealing relay and to turn on an amber warning light when the gas temperature in the exhaust collector exceeds 1300° F. Accurate readjustment is possible only when the switch is calibrated in a high-temperature furnace. However, if nuisance shutdowns are experienced and the exhaust temperature gage indicates that engine exhaust is within maximum temperature limit, the switch can be readjusted to avoid unwarranted shutdown by loosening the center-terminal clamp and gradually turning the adjustment screw recessed in the center of the switch housing. (Turning the screw inward causes the switch to operate at higher temperatures.) Each 1/4 turn of the screw affects the switch closure approximately 50° F. Test kits are provided for this calibration. The switch should be calibrated every 150 hours of operation or monthly, whichever occurs first.

ENGINE OVERSPEED SWITCH.—At approximately 2300 generator shaft rpm, this unit functions to open the safety circuit to the sealing relay and to turn on an amber warning light. After any overspeed trip, the switch must be manually reset by depressing the button at the center of the switch housing. When the switch is adjusted, the knob should be position-marked. Then with the switch

installed, turn the adjustment knob in approximately one turn and start the engine to determine if the switch is operative. Return the adjustment knob back to the original, or marked, position.

For accurate readjustment, the overspeed switch should be removed from the engine and bench-checked with the equipment capable of driving the shaft of the switch at varying speeds up to 1800 rpm. With a 2 to 1 reduction ratio between the engine output shaft and the overspeed switch drive, the overspeed switch should close at approximately 1580 rpm. However, to compensate for effects of slight vibration, the overspeed switch is adjusted to close at 1640 rpm. Pushing the button at the center of the terminal end of the switch housing will reset the switch for future activation. In addition, the master switch must be turned OFF momentarily to reset the safety circuit and permit engine restarting.

To check for the proper setting and operation of the overspeed switch, proceed as follows:

1. Disconnect the actuating cylinder linkage rod end at the exhaust damper bell crank and safety wire the bell crank around the interstage bleed assembly (single hole in bell crank up) to hold the interstage bleed damper closed.
2. Start the engine and gradually increase the speed until the overspeed switch trips closed and shuts down the engine. (A first-stage speed of 30,000 is usually more than sufficient to overspeed the generator to about 2300 rpm.)

If the switch closes prematurely, loosen the set screw in the side of the switch housing and the two clamp screws which lock the large knurled speed-adjusting ring around the switch housing. With the overspeed switch mounting bracket restrained, hold the terminal end of the switch housing and turn the knurled speed-adjusting ring clockwise, as viewed from the terminal end. One-half turn of the speed-adjusting ring will affect the overspeed limit of the engine approximately 200 rpm (approxi-

mately 145 rpm of generator shaft). When proper adjustment is achieved, tighten the two locking screws and the set screw. If switch closing is delayed beyond 1640 rpm, the speed-adjusting ring should be turned in a counterclockwise direction.

If shutdowns occur, within maximum limits, during engine operation, the overspeed switch can also be readjusted while it is installed on the engine. For example, if the switch closes and causes automatic shutdown when the generator speed is 2100 rpm, the knurled speed-adjusting ring can be rotated clockwise approximately 2/3 of a turn to restore switch actuation to the desired setting. This switch should be calibrated after every 50 hours of operation.

GENERATOR SPEED CONTROL.—The speed control system must be adjusted so that, at full generator load, the entire gas flow passes through the second-stage turbine and the exhaust collector, and the governor controls at the required speed.

With the exhaust back-pressure valves and interstage bleed valves installed and aligned, and the exhaust ducting removed, linkage adjustment can be accomplished as follows:

1. Disconnect the exhaust damper and waste gate actuating links. Position both exhaust dampers full-open and hold the dampers while performing the following operations.
2. Close the waste gates and connect the actuating links to the second lowest holes in the bell cranks, adjusting their lengths as necessary to assure equal and complete closing of both waste gates. If the linkage attaching bolts restrict the movement of the waste gate levers, reverse the bolts to obtain sufficient clearance. (This operation will synchronize the waste gates and exhaust dampers so that the following conditions are satisfied: (a) the waste gates are closed tightly with the exhaust dampers wide open, or vertical; and (b) the waste gates are

wide open when the exhaust dampers are about 2/3 closed, and remain approximately vertical while the exhaust dampers move to the CLOSED position.)

3. Hold the actuator piston in the normal extended position (0.30 inch from the top of the cylinder cavity), and connect the exhaust damper actuating links to the bell cranks, adjusting their lengths as necessary.
4. Connect the governor control arm link to the control arm. Adjustment of this link must be made after trial run.
5. The exhaust damper link adjustment should stop the downward stroke of the piston approximately 0.30 inch from the bottom of the cylinder cavity. This setting may have to be changed if trial operation indicates that the exhaust damper closure is incorrect. If the exhaust damper is not sufficiently closed, no-load generator speed may be excessive. If the damper closes too far, the actuator piston force cannot overcome exhaust gas pressure against the damper.
6. Manually cycle the speed control linkage to determine that it operates freely without binding or sticking, and see that the movement of the exhaust dampers and waste gates are synchronized throughout their range of travel.

Whether the governor speed setting requires readjustment can be determined only after a trial run with the exhaust damper and waste gate actuating linkage properly adjusted. If the generator speed is not controlled within the limits of 1860 and 2140 rpm (full-load to no-load speed range) during the trial run, the governor speeder spring tension should be changed in relation to the position of the actuating linkage. This can be accomplished either by repositioning the governor control arm on the shaft serrations, or by changing the length of the control arm link.

If low oil pressure causes a sluggish response in the generator speed control system, the pressure setting of the system relief valve should be checked. Attach a 0 to 500 psi oil pressure gage to the tee fitting at the top of the hydraulic actuator. With one engine stopped and the other operating at practically maximum speed without electrical load, observe the system pressure. If the pressure is less than 450 psi, readjust the relief valve by removing the cylindrical cap on the end of the valve housing and turning the adjusting screw clockwise. (Optimum pressure is between 450 and 475 psi.) After readjusting the relief valve, reinstall the adjusting screw-cap, stop the engine, and remove the pressure gage.

Prior to installation, replacement units should be set to relieve at 450 psi. If necessary, a final readjustment can be made under system pressure operating conditions.

Maintenance Procedures and Precautions

If you are assigned to operate or maintain a gas turbine installation, you must be familiar with the general maintenance precautions for the specific installation. Detailed maintenance procedures for a specific installation may be obtained from the appropriate manufacturer's instruction book.

CARE OF STAINLESS STEEL.—Graphite particles deposited on stainless steel will carbonize the steel at high temperatures. Such deposits destroy the corrosive resisting properties of stainless steel. Therefore, a lead pencil, or similar material, should not be used to mark on stainless steel. Grease pencil marking has been found to be satisfactory when the marking is removed, prior to the installation of the part, by a suitable degreasing process.

Zinc in contact with stainless steel causes rapid and severe corrosion at temperatures above 850° F. Therefore, care must be exercised to avoid rubbing or scraping zinc-plated parts against stainless steel parts.

An antiseize compound that contains zinc, if used in bolting stainless steel parts, will also cause rapid and

severe corrosion at temperatures above 850° F. Anti-seize compound MIL–C–5544 (or approved equivalent) should be used for bolting parts that operate at temperatures up to 1250° F, and which have not been treated to resist galling.

CARE OF O-RINGS.—When installing O-rings, every precaution should be taken to prevent excessive stretching, nicking, scratching, pinching, cracking, and other damages to O-rings. As far as seal leakage is concerned, careful handling and installing of O-rings results in more reliable operation of the engine.

In addition, do not slide or roll an O-ring over threaded surfaces. Before attempting to slip an O-ring into place, over the threads, threads should be covered with paper, thin plastic sheet, or preferably shim stock.

Cleaning and Inspection of Gas Flow Components

The gas flow components of the engine include the burner shells and liners, cross fire tube, nozzle box, interstage bleed assembly, exhaust collector, and first- and second-stage turbine wheels. These components must be thoroughly cleaned after they are removed from the engine. In reassembling the engine, cleanliness is a major factor. Cleaning is essential for proper inspection because it contributes to the life and efficiency of the engine. Dirt and grease deposits on the surfaces of the component parts are fire hazards and reduce the amount of heat radiated from the surfaces. Carbon deposits reduce gas flow and thereby reduce burning efficiency.

When parts are coated with a carbon deposit, baked oil-residue, scale, or other foreign matter, and where surface finishing requirements permit, the best method of cleaning is by blast cleaning with a water and grit mixture, using a 625 mesh (or finer) grit. If water and grit blast cleaning equipment is not available, fine dry sand or garnet grit (No. 90 or finer) are permissible for blast cleaning.

Threaded or bearing surfaces must not be blast cleaned.

These surfaces must be protected by masking with heavy tape or with a fiber soft aluminum, or copper sleeve. Unless extreme care is used during the cleaning operation, blast cleaning tends to hide fine defects by peening-over or smearing. Always use the lowest possible air pressure, consistent with thorough cleaning, and do not concentrate the blast in any one area, especially on thin sections such as blade edges. In order that the fine defects associated with turbine wheels and nozzle vanes will not be hidden, these components must be cleaned with extreme care.

Parts that are to be inspected by Zyglo, Dy-check, or by any other penetrant method must be thoroughly degreased immediately prior to inspection. Vapor degreasing, or washing the parts in naphtha are suitable degreasing methods. Acid or alkali solutions should NOT be used to clean the engine parts because such solutions impair the efficiency of the inspection operation. Any areas which are to be welded must first be mechanically cleaned and degreased.

If blast cleaning equipment is not available, the parts must be cleaned with a wire brush, emery paper, steel wool, or cleaning solvent. Stainless steel wire brushes or stainless steel wool should be used in order to avoid contaminating the surfaces of the parts. (All gas flow components are corrosion- and heat-resistant alloy steel.)

Additional information concerning inspections of gas flow components, as well as inspection schedules, may be obtained from either the ship's Inspection Guide or the manufacturer's instruction book.

CLEARANCES, TORQUES, AND BALANCE.—On gas turbine engines, proper clearances must be strictly maintained. Improper clearances will result in damage to vital parts of the engine. The clearances for gas turbine engine components can be obtained from the appropriate manufacturer's instruction book. Whether clearances are measured during the installation of the engine compon-

ents, or as required by engine malfunction, or at overhaul, they should be measured when the equipment is cold.

The manufacturers' instruction books contain special torque values which should be followed when tightening any of the bolts and nuts of the turbine and the combining gear components. Since aluminum alloy metals are employed in this engine, the use of improper torques may result in engine failures. Therefore, you must adhere strictly to the special torque values, applicable to the gas turbine engine.

As far as balance requirements are concerned, perfect balance must be maintained because the engine is operated at high speeds. An important design requirement of the rotor assembly (includes first-stage turbine wheel and shaft, accessory drive pinion and key, compressor bearing, oil slinger, impeller and key, washer, thrust and fairing nuts) is that it must be statically and dynamically balanced to within .02 ounce-inch.

In addition, the design requirements of the second-stage turbine wheel and shaft, with floating bearing retainer nut and set screw, are that they must be statically and dynamically balanced to within .05 ounce-inch.

Except for the impeller or first-stage turbine wheel, any part of the rotor assembly may, with little likelihood of unbalance, be replaced without static and dynamic balancing. If two or more parts are replaced, the entire assembly must be rebalanced.

SAFETY PRECAUTIONS

When working with a gas turbine installation, give special consideration to the inlet pressure and the exhaust gases, as well as to the relatively high speed and temperature of certain sections of the gas turbine engine.

Inlet Pressure

During engine operation, a negative pressure area is created immediately forward of the engine air inlet. When the engine is installed in the power package, ade-

quate screening at the air inlet bell prevents articles from entering the compressor. When operating the engine on a test stand, the screened air inlet bell should always be secured to the engine. Loose clothing, white hats, and ties should not be worn or carried near the air inlet, while the engine is running. In addition, shirt pockets should be free of any articles.

Overspeed Damage

Excessive overspeed of the engine can result in the failure of the compressor impeller or either of the two turbine wheels, with the possibility of pieces being thrown outward by centrifugal force. Failure of the compressor impeller may shatter the compressor case or elbows. If a blade is thrown from a turbine wheel, it will probably be discharged with exhaust gases and cause no external damage. At maximum engine speeds, stand clear of those areas adjacent to the planes of rotation of these components.

Surface Heat

Heat shields around the nozzle box and exhaust collector, as well as the insulation on the exhaust ducts, provide reasonable protection from surface heat. However, touching any portion of the engine which conducts combustible gases, or adjacent parts, can result in severe burns. A cooling period of approximately 30 minutes is required before inspecting or performing major maintenance.

Exhaust Gases

Direct contact with the high temperatures and velocities of the engine exhaust gases can result in severe burns and/or shock. Even though the toxic effect of the small amount of carbon monoxide present in the engine exhaust is negligible, avoid continuous exposure to the exhaust fumes because they may cause headaches, eye smarting, or other irritations.

SUMMARY

The gas turbine engine is relatively new in marine applications. However, it may eventually become standard as a source of power in certain Navy applications of internal combustion engines. Since the two-stage turbine engine is currently used aboard MSB–5 class minesweepers, you should be familiar with the principal systems and components of this type of engine.

If you are assigned to operate and maintain a gas turbine installation, you will have to know how to operate as well as maintain certain equipment. Detailed operating and maintenance instructions may be obtained from manufacturers' instruction books.

QUIZ

1. What are the component parts of the gas turbine-generator unit used to supply motive power for the generators in minesweeping operations?
2. The engines of a gas turbine-generator unit are divided into how many sections?
3. The power developed by a gas turbine engine is primarily dependent upon what factor?
4. What controls the flow of combustion gases through the second-stage turbine, as required, to maintain a constant output shaft speed for all generator load variations?
5. What limits the speed of the second-stage wheel and output shaft of a gas turbine engine?
6. By what means is power from the two gas turbine engines combined to drive the generator at reduced speed?
7. What unit of a fuel oil system meters fuel to the nozzles to maintain combustion at the required rate?
8. During engine cranking, if excess pressure is bled from the governor outlet line to the inlet port of the engine-driven fuel pump, the fuel nozzle pressure will be maintained between what values?
9. What is the desired operating pressure of the fuel supply pump of the fuel oil system?
10. What are the 5 circuits of the electrical system of the Boeing 502 gas turbine?
11. How is the alarm horn of a warning circuit actuated?

12. If automatic shutdown of an engine results from excessive speed or temperature, what must be done?
13. What controls the flow of combustion gases through the second-stage turbine?
14. If an abnormal start has been encountered, what should be done?
15. Upon starting, what will happen when the oil pressure is low and the switch released prematurely?
16. If automatic shutdown occurs on one engine, what should be done?
17. Immediately after an automatic shutdown, the operation of what unit of the dead engine must be checked?
18. Restricted throttle movement caused by interference between the governor control arm and the heat shield of the nozzle box can be corrected by taking what action?
19. What is installed in the starting fuel-bypass line to maintain the fuel pressure at 50 to 150 psi during engine starting operations?
20. Under maximum speed conditions, what is the maximum allowable pressure at which the engine oil pressure-scavenge pump should deliver oil, through the engine oil cooler and filter, to the oil manifold?
21. How often should the engine oil thermoswitch be calibrated?
22. The engine overspeed switch functions to open the safety circuit to the sealing relay whenever the generator shaft speed exceeds what rpm?
23. If blast cleaning equipment is not available, what can be used to clean gas flow components?

CHAPTER 11

AUXILIARY MACHINERY AND EQUIPMENT

Aboard ship there are a number of auxiliary machinery units, some of them located outside the engineering spaces, with which the EN2 must be familiar. This machinery includes the compressed air plants, steering gear, anchor windlasses, deck winches, capstans, cranes, elevators, and Diesel emergency generators. This chapter furnishes general information on the care and maintenance of compressed air plants, steering mechanisms, hydraulic systems, and Diesel emergency generators.

COMPRESSED AIR PLANTS

In working with any of the compressed air systems (low-, medium-, and high-pressure), you probably found that the primary source of trouble was the compressor. Although the design and capacity of compressors vary, the maintenance procedures are essentially the same. However, remember that the care and maintenance of high-pressure compressors require additional safety precautions, and the procedures recommended by the manufacturer should be followed.

Before proceeding with the maintenance of the component parts of a compressed air plant, it is important to emphasize the proper use of tools. When a machine of any kind is being serviced, not only the proper use but also the use of proper tools should be kept constantly in mind. The use of improper tools and methods can cause, and has

resulted in, serious casualties to auxiliary as well as other machinery.

While modern auxiliary machinery is rugged and dependable, it is not designed to withstand abusive treatment. Gasketed joints, pipe joints, and bolts are designed to safely withstand the strain required for a tight connection when the specified torque is applied with the correct tool. The application of a force in excess of that prescribed usually results in breakage. If a joint or bolt cannot be tightened without using an oversized wrench or wrench handle extension, the unit has been improperly assembled. In addition, there probably is something wrong with the flanges.

In newly designed high-pressure air compressors, extensive use is made of soft copper gaskets for sealing joints subject to pressures up to 3000 psi. These gaskets make a tight and dependable seal if the joint is tightened down properly. However, as the tightening pressure is applied to the joint, the copper gasket is compressed and becomes work-hardened. Therefore, if the joint is broken and the gasket reused, a greater tightening force is required to make a tight seal. If a wrench extension is used, it is possible to distort the gasketed surface or twist off the bolt without achieving a tight joint. Therefore, whenever remaking copper-gasketed joints, new copper gaskets should be used, if available. In an emergency, the used gaskets can be made fit for reuse by annealing (red heat) to the soft condition. (This is an emergency measure and should not be resorted to as a general practice.)

Maintenance of Parts

The overall problem in maintaining compressed air systems is to take the necessary steps to prevent a reduction in compressor capacity. To keep a ship's air compressors operating efficiently at all times and to prevent as many troubles as possible, it is necessary to properly care for air intakes and filters; to maintain and replace

air valves; to maintain air cylinders, pistons, and wrist pins; to adjust bearings and couplings; and to properly maintain the lubrication, cooling, and control systems.

AIR FILTERS AND INTAKES.—Satisfactory operation of any compressor requires a supply of clean, cool, dry air. To help keep the air supply clean, filters are fitted to compressor intakes. Unless these filters are inspected and cleaned regularly they will become clogged and cause a loss of capacity.

To clean filter elements, remove them from the intake and wash them with a jet of hot water or steam, or immerse the elements in a strong solution of sal soda. The filter body should be drained and replaced. Filter elements of the oil-wetted type should be dipped in clean oil after cleaning. Before replacing the element in the intake, let excess oil drain from it. The use of gasoline or kerosene is prohibited for cleaning air filters, because of explosive fumes which may collect in the compressor or air receiver.

Care must also be taken to prevent the entrance of rain or spray into the intake pipe, and means should be provided for draining the intake pipe of any water that may collect in it. When air intake pipes are led from the weather deck, the intake duct or pipe should be the full diameter of the compressor intake connection, and as short and direct as possible.

RECEIVERS.—These units should be drained regularly. The frequency of draining is generally determined for each installation. (When air compressors are not equipped with after-coolers, receivers will require more frequent draining.) The safety valve should be tested, at regular intervals, by lifting the hand lever or by raising the pressure to that required to operate the valve.

During the sixth year of service and approximately every three years thereafter, all low- and medium-pressure receivers must be given a hydrostatic test of $1\frac{1}{2}$ times the designed working pressure.

High-pressure air flasks and separators should be inspected internally for the presence of corrosion. This inspection should be made at an interval of no more than six years and at intervals of approximately three years thereafter. After these units have been disconnected and reconnected, they should be subjected to a hydrostatic test of $1\frac{1}{2}$ times the designed working pressure.

AIR VALVES.—The inlet and discharge valves of compressors require special attention. When valves leak, compressor capacity is reduced and pressure is affected. Deviation from normal intercooler pressure may indicate a leaking or broken valve, rise in pressure indicates a defective inlet valve, decrease in pressure indicates a defective discharge valve. Another sign of valve trouble is an unusually hot valve cover.

Dirt is generally the cause of leaking valves. When valves become dirty, the source of trouble can generally be traced to dirty intake air; use of an excessive amount, or of an improper grade, of cylinder oil; or excessively high air temperature, resulting from faulty cooling. Periodic inspection and cleaning of valves and valve passages minimizes the number of air valve troubles.

When air valves are removed for inspection, mark each valve to ensure that it will be replaced in the same opening from which it was removed. Inspect valves carefully and do not disassemble them for cleaning unless their condition necessitates such action. Dirt or carbon can usually be removed from valve parts without disassembling the valve. If it becomes necessary to disassemble the valve, note the arrangement of the various parts so that the proper relationship will be kept when the valve is reassembled. To remove carbon from valve parts, soak the individual part in a suitable solvent then brush or scrape lightly. After drying and reassembling the valve parts, test the operation of the valve to see if it opens and closes freely.

Before replacing air valves in a cylinder, inspect the

gaskets and replace any which are damaged. Copper-covered asbestos or plain, thin copper gaskets should be used. If these are not available, 1/16-inch compressed-asbestos sheet gaskets may be used temporarily. Each valve assembly should be inserted in the same hole from which it was removed. Since it may be difficult, in many cases, to distinguish between suction or discharge valves, extreme care must be taken when the valves are being inserted in the cylinder. Make certain that suction valves open TOWARD, and discharge valves AWAY FROM, the center of the cylinder; otherwise serious damage or loss of capacity will result. Then place the valve cover on the cylinder, making certain that its gasket is squarely in place; draw down the opposite cover nuts evenly, and in turn, so as not to tilt the cover. Tighten down the valve setscrew or clamping bolt, drawing it tight to hold the valve on its seat. If special lock nuts are not provided to seal against leakage at the threads of the valve setscrew, a turn of solder or fuse wire should be placed around the screw and set down into a recess by the locking nut.

CYLINDERS AND PISTONS.—The procedures for removing pistons, fitting new piston rings, replacing cylinders, and checking the piston end and ring clearances are relatively the same as for internal combustion engines. Since these items have been covered in detail in chapter 8 of this training course, only a general discussion of the maintenance of air compressor cylinders and pistons will be given here.

The maintenance procedures for removing heads vary with each design, therefore, it is essential to first consult the manufacturers' instruction books before inspecting the cylinders and pistons. Before removing heads, water should be drained from the compressor. When removing heads, care should be taken, particularly where metal-to-metal joints are involved, to prevent damage to the joint. Where joints are fitted with a gasket, these can occasionally be saved by running a knife blade in, between the

gasket and head, after the head has been lifted not over $\frac{1}{4}$ inch.

The CLEANING OF CYLINDERS with kerosene, benzine, or other light oils is prohibited. These light oils vaporize very quickly and are easily exploded. The interiors of compressors may be wiped with clean, dry rags. A satisfactory method for cleaning cylinders is to fill the lubricator with strong soapsuds (1 part soft soap to 15 parts water), or soda solution, allowing this to feed freely while the compressor operates unloaded, at slow speed, with the separator drain valves open. This cleaning method is very effective, however, oil should always be fed again for 30 minutes before securing in order to prevent the interior surfaces from rusting. The sight feeds in the lubricator must be refilled after the cylinders have been cleaned.

To REMOVE TRUNK PISTONS from vertical compressors, it is first necessary to remove the cylinder heads. In case three- or four-stage compressors are used, the third and fourth stage cylinders will also have to be removed. Proceed to turn the compressor (by hand) to top center. Then remove the lower half of the crank pin bearing (on some designs, it may be necessary to remove the entire crank pin bearing box). The piston and connecting rod can then be pulled up through the cylinder. In removing the pistons from compressors fitted with crossheads and piston rods, the general procedure is to loosen the piston rod locknuts adjacent to the crosshead, then unscrew the piston rod from the cross head, and lift the piston and the rod out of the cylinder.

If a REPLACEMENT OF PISTON RINGS is required because of their being worn or broken, accurate measurements of the cylinder liners should be taken. Standard size rings may be used in oversize cylinders if the oversize does not exceed 0.003 inch per inch of cylinder diameter. The LINER may also need to be replaced if it is badly worn or out of round. When replacing piston rings, first fit

them to the cylinder to check for proper end clearance. File the ends, if necessary, to make them fit. The side clearance of the rings should be such that the rings will fall easily into the piston grooves, which should be deep enough for the ring thickness. Ring splits should be staggered. After assembly of the piston, wire the rings tight with a soft copper wire, so that they will enter the bore easily. This wire can be removed through the valve ports after the ring has entered the cylinder bore.

When REPLACING CYLINDERS and heads, see that they are all drawn down evenly, especially on multi-stage compressors where the heads contain cylinders for third and fourth stages. Otherwise, excess wear on the cylinders and pistons will result.

When a piston has been replaced in a compressor, the PISTON END CLEARANCE must be checked. This is done by inserting a lead wire through a valve port or indicator connection. Jack the compressor over, when the piston has moved to the end of its stroke, the lead will be flattened to the exact amount of clearance. The wire should be long enough to permit a reading near the center of the piston. (These readings should also be taken after any adjustment or replacement of the main, crankpin, wrist pin, or crosshead bearings.) By referring to the assembly drawing of the compressor, the point at which the clearance will be the least can be determined. In differential piston compressors in which the compression takes place in two stages during the same stroke, this clearance must be measured in both stages. In double-acting compressors, or in those in which compression in any stage occurs on the reverse stroke, it is necessary to take a second reading of the clearance at the bottom center of the stroke (nearest the crankshaft), in the applicable cylinder. Having these readings, the piston end clearance can then be adjusted. Proper clearances for the specific compressor can usually be found in the manufacturer's instruction book, or on the assembly drawings.

If the specific instruction book or drawing is not available, adjust the clearance so that it is about 1/64 inch greater at the top end of the stroke than at the bottom end of the stroke. This is necessary in order to allow for expansion of the running parts when the compressor is operating.

BEARINGS.—Inspection of bearings, as well as other running parts of the compressor, should be made at regular intervals, at which time any replacement of worn parts, and adjustment of bearings should be made.

Shell-type main and crank pin bearings are adjusted by taking out thin metal shims between the top and bottom halves of the bearing. The same number of shims should be removed from each side of the bearing. After replacing the bearing caps, the bearing stud nuts or bolts should be set up tightly and locked. The caps should be clamped down hard so they cannot work loose. After adjusting the bearing, the compressor should be jacked over to make certain that no binding results.

When the compressor is started (after the bearings have been adjusted), watch the bearings carefully and see that they are not too tight, and do not overheat. During this starting period, the compressor should be stopped occasionally and the crankcase covers removed. In addition, the bearings should be felt in order to see if they have overheated. The bearing-cap nuts should never be loosened to make a bearing run cool. Loose caps may cause bearing stud and bolt breakage as well as damage to the compressor. When all shims have been removed, further adjustment is impossible and the bearing must be renewed or rebabbitted. When this is necessary, it is more satisfactory to replace all the main bearing shells. This, in turn, ensures proper alignment. In order to fit a new main bearing properly, it must be scraped so that it fits the shaft and lines up with the old bearings.

Ball bearings are used for main bearings only on small low-pressure and medium-pressure compressors. Ball bearings require no adjustment. The only care required for these types of bearings is proper lubrication. Ball

bearings are replaced by pressing off the old bearings and pressing or shrinking on the new ones. When ball bearings are removed or replaced, apply force to the inner race only; this prevents damage to the bearing.

Instructions for the care, adjustment, and replacement of taper roller main bearings, where installed, may be found in the manufacturers' instruction books for the specific compressor. The bearings are generally mounted on the crankshaft by heating them in an oil bath at a temperature of 200° F, then dropping them in place.

WRIST PINS.—It is generally impossible to adjust for wear on wrist pins or bushings. When these parts are worn to the point of becoming noisy, they should be replaced. In making a replacement, see that the oil hole is properly lined up with the hole in the connecting rod. After being pressed into the rod, the new bushing must be reamed.

CROSSHEAD SHOES.—These parts are provided with shim or wedge adjustment. Wear should generally be very slight. However, adjustments should be made when it is noticed that, as a result of wear of the crosshead shoe, the travel of the piston rod causes a movement in the stuffing boxes.

REDUCTION GEARS AND COUPLINGS.—Alignment of the reduction gear and pinion should be checked periodically, especially on a new compressor. Misalignment may result from settling, straining, or springing of foundations, and bearing wear.

Flexible couplings, when properly lined up, require very little maintenance. Certain types of couplings require occasional lubrication to prevent excessive wear of springs or bushings. Coupling bushings should be renewed when wear causes the coupling to be noisy.

V-BELTS.—These drives require adjustment for belt tension. During the first few months of use, belts stretch slightly. A loose belt will slip on the motor pulley and cause undue heating and wear on the belt. A tight belt

will overload the bearings. V-belts should be protected against oil, and from temperatures above 130° F, to prevent rapid deterioration. When renewing V-belts, install a complete new set.

CONTROL DEVICES.—Because of the great variety of control, regulating, and unloading devices used with compressors, detailed instructions on their adjustment and maintenance must be obtained from manufacturers' instruction books.

If a control valve fails to operate properly, it will probably be necessary to disassemble and clean the valve thoroughly. Some control valves are fitted with filters filled with sponge or woolen yarn, to prevent dust and grit from being carried into the valve chamber. These filters also remove the gummy deposit which comes from the oil used in the compressor cylinders. The filter element should be replaced with the specified material each time a valve is cleaned. Do not use cotton, because it will pack down and stop the air flow.

Since relief valves are necessary to ensure safe operation of a compressed air system, they must be maintained in satisfactory operating condition. Relief valves should be set as specified by the manufacturer. They should be tested manually each time the compressor is started, and the individual valve setting should be checked periodically by raising the pressure in the spaces to which the valves are attached.

PACKING AND GASKETS.—Some double-acting air compressors have piston rod packing glands which may require replacement. The manufacturers' instruction books should be referred to before replacing packing, as, especially in old designs of high-pressure compressors, metallic packing may be required. Where soft packing is satisfactory, however, use Navy symbol 1430, 1433, 1104, or 1100, or alternate rings of 1430 and 1433.

When replacing stuffing-box packing, the rings should be put in so that the joints will not be in line. The pack-

ing must not be crowded too tightly at first because it will become hard as a result of the squeezing out of the lubricant. The gland should be drawn up only slightly. After the compressor has warmed up, it should be tightened sufficiently to prevent blowing.

In replacing gaskets (head gaskets as well as frame gaskets), see that the new ones have the identical thickness as those furnished by the compressor manufacturer. This will ensure proper clearance between pistons and heads. The following gasket materials are suitable for use on air compressors:

1. Air valve seats—thin copper, soft annealed; copper-covered asbestos; asbestos sheet (1/16 inch thick) for emergency or temporary use only.
2. Valve covers—same as above.
3. Cylinder head joint—compressed asbestos sheet.
4. Frame joints—plant fiber sheet.

Since rubber gaskets deteriorate rapidly when subjected to oil and heat of compression, they should not be used on air compressors. When replacing gaskets, see that no air or water passages are obstructed. Gaskets used in air lines should be made of plant fiber (because of the oil, asbestos packing will not last in air lines).

Care of Cooling and Lubrication Systems

The care and maintenance of these systems are relatively the same as for similar systems in internal combustion engines. In the case of air-cooled compressors, however, measures must be taken to keep the cooling fins clean. Oil and dust are effective insulators; if they are allowed to collect on the fins, they will prevent heat transfer.

For the compressor cooling system, general requirements for care and maintenance are as follows:

1. Periodic inspections should be made of intercoolers and aftercoolers.
2. Collections of gummy oils or tarry substances on the sides of cooler tubes should be removed by washing

the tube nests with a cutting solution. (In the case of coolers in which the air flows outside the tubes, it is best to spray the solution over and around the tubes, and, if necessary, a narrow, stiff-bristle brush may be used.) Make certain that the tube nests are completely dry before reassembling them.

3. Leaks in the tube nests must be repaired; otherwise, water will leak into the compressor while it is secured, and air will leak into the waterside during operation.
4. Cylinder water jackets should be inspected and cleaned periodically with a cleaning nozzle.
5. When a drained compressor water-cooling system is being filled, the water inlet valve should be opened slightly to allow the water to rise slowly in the cooler shell and water jackets. In addition, the vent valves fitted to the water spaces should be opened so that entrapped air can escape and air pockets will not form in the system.
6. If, during operation, a water-relief valve on a cooler blows while the cooling water pressure gage indicates normal pressure, it is evident that a burst tube is permitting the air pressure to suddenly increase the water pressure within the shell. In this case, the compressor should be secured immediately and the tube plugged. (In the case of coil-type coolers, the coil should be replaced.)

The lubrication system of a compressor should give little trouble if the following steps are taken:

1. Keep the reservoir oil at the prescribed level.
2. Change the crankcase oil periodically, and at the same time flush the crankcase and clean the oil filter. (During operation, the oil filter should be cleaned to prevent a reduction of oil flow. On recent designs of compressors this oil filter is generally of the multiple-disk, edge-filtration type, and can be cleaned by whirling the handle.)

3. Maintain correct lube oil pressure by keeping the oil pump in good working condition and by adjusting the bypass relief valve. (If the compressor has been in use for some time, and the correct lube oil pressure cannot be maintained, disassemble the pump and check for excess wear.)
4. Keep the oil cooler free from leaks to prevent oil contamination and emulsification.
5. Replenish as necessary the glycerine and water in the lubricator sight feeds.
6. Keep the lubricator adjusted to give the specified quantity of oil feed.

Safety Precautions

Since explosions are a potential hazard, especially in high-pressure systems, every possible precaution should be taken to prevent them. To help prevent explosions and to maintain a compressed air plant in satisfactory operating condition, the following safety precautions should be observed:

1. Minimize the possibility of explosions in an air compressor, discharge line, or receiver by preventing or eliminating:
   a. Dust-laden intake air.
   b. Presence of oil vapor in compressor or receiver.
   c. Leaky or dirty valves which result in abnormally high temperatures.
2. See that the compressor intake receives only cool, clean, and dry air.
3. Use only the minimum amount and proper grade of oil for cylinder lubrication.
4. Do not use benzine, kerosene, or other light oils to clean compressor intake filters, cylinders or air passages.
5. Secure a compressor immediately if there is an abnormal rise in the temperature of air discharged from any stage.

6. Install no stop valve or check valve between the compressor and receiver, unless a relief valve is fitted between the compressor and the stop or check valve. Otherwise, if the compressor is started against a closed valve or a deranged check valve, the air cannot escape and an explosion will result.
7. Never leave the compressor station after starting a compressor—especially one that is new, or one that has been idle for some time—without making certain that control, unloading, and governing devices are working properly.
8. Do not service or remove any part of a compressor unless the following precautions have been taken:
   a. Leave pressure gages open to the spaces to which they are attached.
   b. See that the compressor is actually secured and cannot be started automatically or accidentally.
   c. See that the compressor is blown down completely.
   d. See that all valves, including the control or unloading valves, between the compressor and receiver are closed.
9. Prevent damage from excessive temperatures by operating a compressor at recommended speeds and maintaining proper cooling-water circulation.
10. Drain the circulating water system of a compressor if it is to remain idle for any length of time, or if it is to be exposed to freezing temperature.

HYDRAULIC AND OTHER AUXILIARY MACHINERY

Some of the auxiliary machinery, such as steering gear and anchor windlasses, are required to operate at variable speeds over a considerable range. In addition, there must be close control of speed between maximum and minimum limits. The common requirements of this auxiliary machinery are a high starting torque and the ability to accelerate to maximum speed quickly. To meet

these requirements in modern Navy vessels, the electrohydraulic drive has been adopted. (Some older ships, still used by the Navy, are equipped with electromechanical or steam-driven steering gear.)

The paragraphs which follow contain general information concerning the operation and maintenance of electrohydraulic equipment. Detailed information concerning maintenance and repairs of specific equipment can be obtained from the manufacturers' instruction books.

Electrohydraulic Speed Gear

Rotary motion, transmitted by hydraulic equipment is accomplished by use of a combination of a hydraulic pump —"A" end, and a hydraulic motor—"B" end (fig. 11-1). Information concerning the principles of operation of this type pump (axial-piston variable stroke pump) can be obtained by referring to chapter 5, Pumps, of this training course.

The "B" end, which is permanently on stroke, will be made to rotate by the hydraulic force of the oil acting on

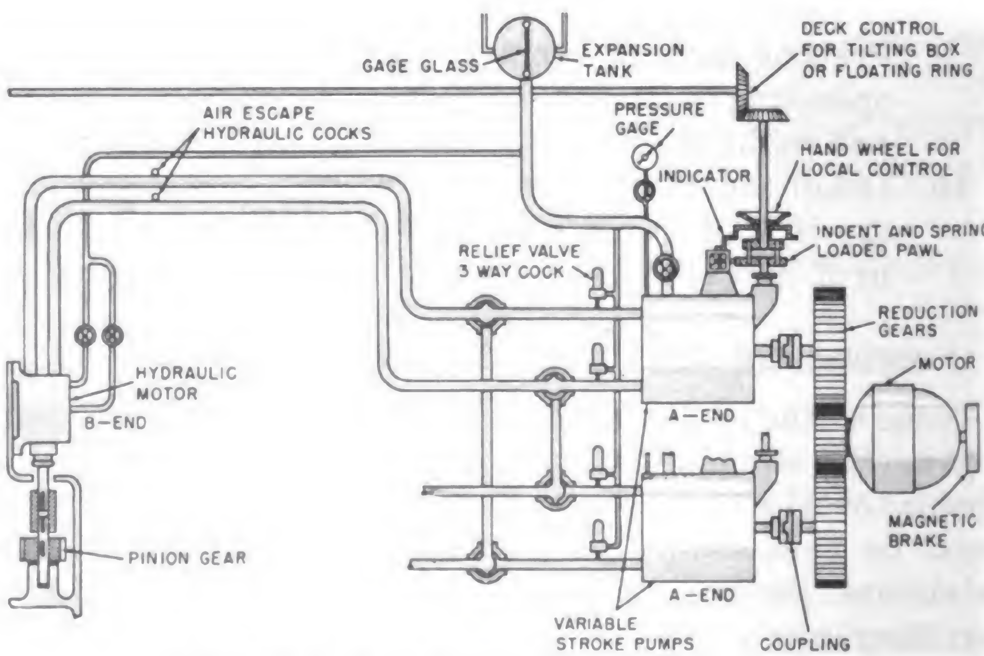


Figure 11–1.—Typical hydraulic power transmission.

its pistons. Movement of the pistons "A" end is controlled by a tilt box in which the socket ring is mounted. By moving the tilt box one way or another, and by the amount of angle at which the tilt box is placed, the length of the piston movement is controlled. This in turn controls the amount of fluid flow. The "A" end is always in motion, but with the tilt box in a neutral or vertical position no oil is pumped to the "B" end. Any movement of the tilt box, regardless of how slight, causes pumping action to start, and therefore immediate action in the "B" end.

When reciprocating motion is desired, such as will be found in a steering gear, the "B" end is replaced by a piston or a ram. The force of the hydraulic fluid causes the movement of the piston or ram. The tilt box in the "A" end can be controlled either locally as on the anchor windlass or by remote control as on the steering gear.

Steering Gear Mechanisms and Remote Control

Strictly speaking, the steering gear is the mechanism which transmits power from the steering engine to the rudder stock, though the term is frequently used to include the driving engine and the transmitting mechanism. The following three types of steering gears may be found.

1. Electrohydraulic
2. Electromechanical
3. Steam-driven

In modern naval vessels, however, practically all steering mechanisms are hydraulically driven. Constant-speed electric motors drive variable-stroke rotary pumps, which furnish the hydraulic power to the steering gears. Some steering gears now use constant delivery vane pumps.

On most modern Navy vessels, remote control of steering gears is accomplished either electrically by means of an alternating-current synchronous transmission system, or hydraulically by means of a telemotor system. Remote control of the steering gear (from the steering

wheel on the bridge) may be accomplished electrically by means of a direct-current pilot motor and its controller.

The A-C SYNCHRONOUS-TRANSMISSION type of remote control is simple and reliable. It consists of self-synchronous type transmitters located in the several steering stations and controlled by the motion of the wheel, suitable electric leads, and a self-synchronous receiver, connected through a differential type follow-up mechanism, to the control shaft of the variable-stroke hydraulic pumps. Motion of the steering wheel, which is mounted on an extension of the shaft of the transmitter rotor, is therefore transmitted electrically to the steering-engine control mechanism. The follow-up system maintains the movement of the rudder proportional to that of the steering wheel, so that rudder movement is stopped as soon as the rudder matches each motion of the wheel. Electrical control cables between the pilot house and the steering room are generally installed in duplicate (port and starboard), with suitable selector switches provided in the steering room and pilot house.

The HYDRAULIC TELEMOTOR type of remote control is installed aboard many auxiliary ships of the Navy. The telemotor system consists of two hydraulic cylinders, the transmitter and the receiver, each fitted with a piston and connected by copper pipes. The transmitting cylinder is located near the steering wheel, and the receiving cylinder near the engine. Movement of the wheel displaces the piston of the transmitting cylinder, exerting force against a quantity of fluid, which in turn produces a corresponding movement of the piston in the receiving cylinder. The displacement of fluid in the latter cylinder causes operation of the engine control mechanism.

The telemotor system is simple and its pipes or tubing may be led through bulkheads where the watertight integrity of the ship will be least affected. There are two types of hydraulic telemotors: (1) the internally packed type which employs a piston equipped with a leather

formed to the inside of the cylinder, and (2) the externally packed type which employs a ram that is packed at the open end of the cylinder.

In recent telemotor installations, a constant delivery, axial piston pump, similar to the "B" end of a hydraulic power transmission system, is used as the transmitter. With this system, possible leakage is reduced to a minimum because no pump packing is required.

A complete telemotor system, illustrated in figure 11–2, includes telemotors, interconnecting piping, valves, a charging tank with sufficient capacity to fill the system, a charging pump, and a replenishing tank.

When a hydraulic telemotor system is being installed, it is necessary that considerable care be given the piping in order to ensure satisfactory operation. No fitting should be used which restricts the pipe area. Piping should be installed as straight as possible, always leading up from the receiver to the transmitter, without dips which might form air pockets. Piping should be securely braced to prevent excessive vibration, and installed in areas protected from extreme cold and heat. The pipe lines must not run close to the steam lines or the smokestacks.

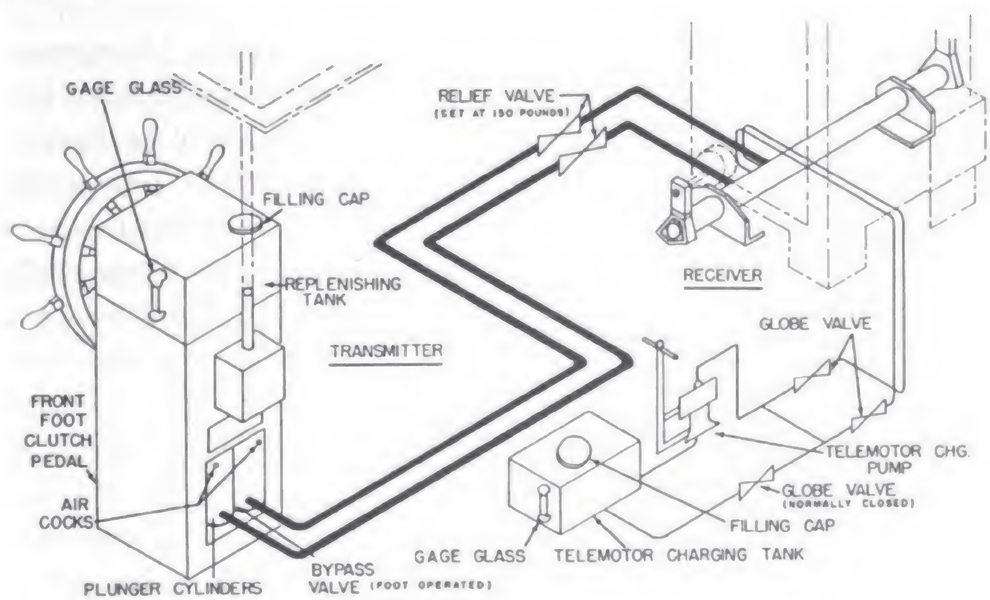


Figure 11–2.—Hydraulic telemotor system.

In addition, care must be taken to prevent kinks and sharp bends, in the piping, which will trap air and increase fluid friction. Pipes must be made up tight to prevent leaks, especially at inaccessible locations. Pipes must not be brazed as this reduces the pipe area, allows drops of solder to get into the pipeline, and prevents removal of piping to clean out obstructions.

The replenishing tank (fig. 11–2) is connected to the plunger cylinders by a pipeline consisting of two foot-operated valves for replenishing and synchronizing of the telemotor.

FILLING THE TELEMOTOR SYSTEM from the charging tank is accomplished by opening the air cocks at the transmitter and starting the charging pump. After the oil has appeared at the air cocks, the pumping is continued until the oil is free of bubbles. The air cocks are then closed and the oil allowed to fill the replenishing tank. After the tank has been filled, and the pump is still operating, the valve leading to the replenishing tank is closed, and the system is subjected to a slight pressure.

The effective operation of the telemotor system depends upon the purging of all entrained air and the elimination of leaks. Purging the system of air, under normal operating conditions, is done by opening the valve leading from the replenishing tank, and the air cocks at the transmitter. Since the replenishing tank is located above the highest point of the telemotor system, the air is forced out of the air cocks by the gravity flow of oil. The cocks are closed when the oil flows smoothly without bubbles.

Inspect the valves and joints in the system frequently and ELIMINATE ALL LEAKS that are found. To correct a leaky piston in the internally packed telemotor, see that the leathers are in good condition, and that the springs (if used) keep the leather in contact with the inner wall of the telemotor cylinders. To stop leaks in the externally packed telemotor, tighten the glands sufficiently to cause the packing to be compressed about the rams, until the leak is stopped.

The HYDRAULIC FLUID CHARACTERISTICS are especially important if the telemotor system is exposed to low ambient temperatures. Under such conditions, a high-grade mineral oil having a cold pour point of —24° to —40° F should be used. Military Symbol 2075 H is normally used in telemotor systems, however, under very low ambient temperatures, it may be necessary to use a special oil with the designated cold pour point.

Every possible precaution should be taken to prevent contamination of the oil by condensate or other water. When the system is being filled with hydraulic fluid, the oil should be strained into the charging tank through four to six layers of cheesecloth. In this way, small amounts of water (or air bubbles) and other foreign matter are prevented from entering the system. Such precautionary measures will aid in keeping a hydraulic telemotor system in satisfactory operating condition.

When a telemotor system is first put into operation, and as often as necessary thereafter to ensure proper functioning of the system, the telemotor and the rudder indicators should be synchronized.

The D-C PILOT MOTOR type of remote control is used with some early electrohydraulic steering gears. It consists of a small reversible d-c motor which is connected, through a differential gear, to the control shaft of a variable-stroke pump. The pilot motor is controlled by means of a magnetic contactor control panel located near the motor, and through master controllers located at the steering wheel. The motor has a magnetic brake which holds the motor when the master controller is returned to neutral position.

Electrohydraulic Steering Gear

Most steering gear installations on modern naval vessels are of the electrohydraulic type and use the "A" end of the previously described electrohydraulic speed gear. The development of this type was prompted primarily by the large momentary electrical power requirements for elec-

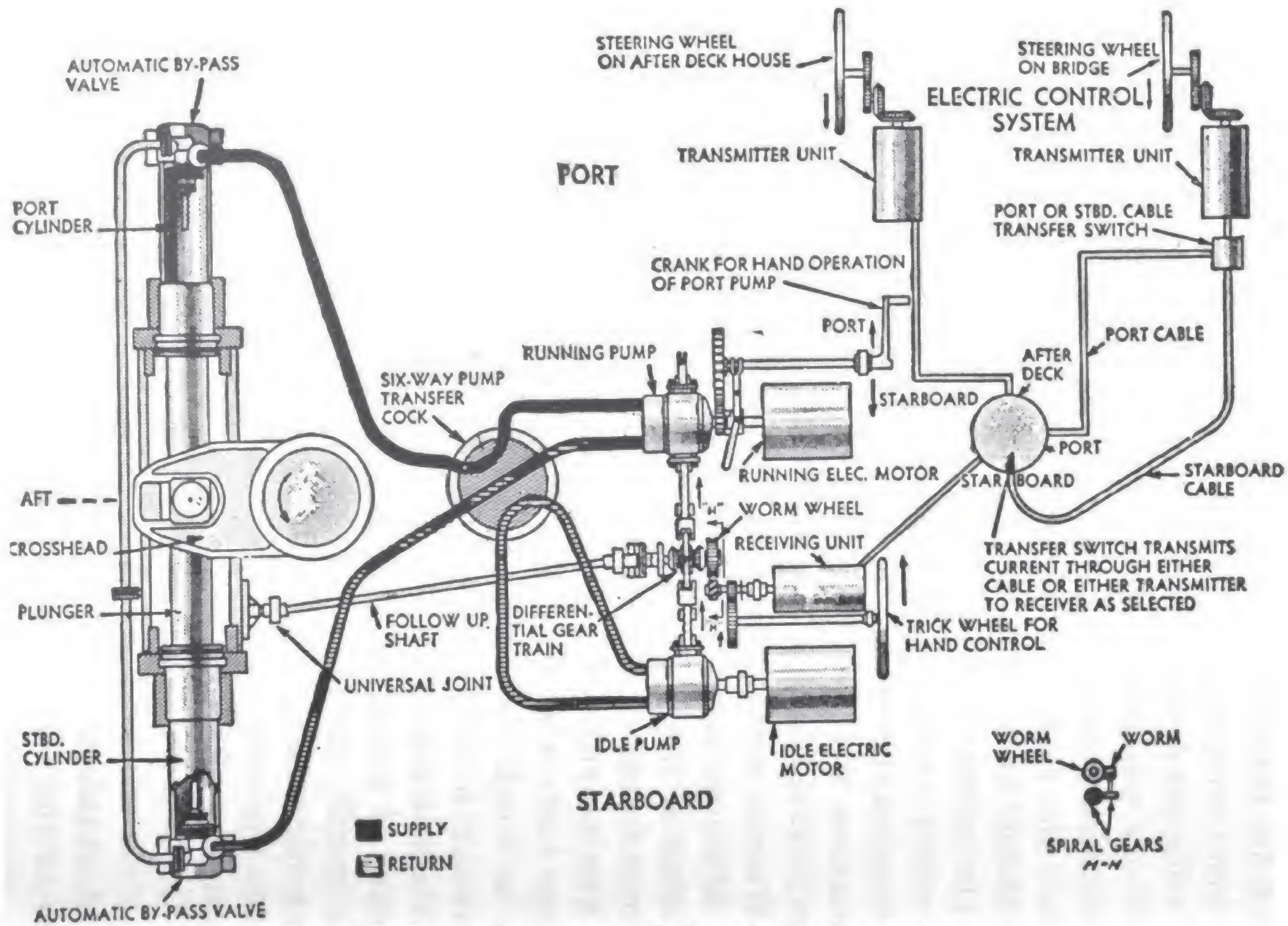


Figure 11—3.—Single-ram type of electrohydraulic steering gear.

tromechanical steering gears—particularly for vessels of large displacement and high speed, with attendant increased rudder torques. Further advantages of the electrohydraulic steering gear are:

1. Little friction and inertia of moving parts, such as in heavy differential screw and gears.
2. Low power consumption peaks.
3. Sensitive response, with little lag, to movements of the steering wheel.
4. Small deck space and head room required.
5. Savings in weight.
6. Flexibility in the arrangement of hydraulic cylinders, pumps, and control mechanisms.
7. Dependability.

There are various types of electrohydraulic steering gear layouts in use, but their operating principles are about the same. Some ships have double hydraulic rams and cylinders mounted fore and aft; others have double-cylinder single rams mounted athwartships. Some systems use axial piston variable-stroke pumps, others use radial piston pumps. Figure 11–3 illustrates a single-ram type of electrohydraulic steering gear.

A diagrammatic arrangement of a double-ram type of electrohydraulic steering gear (with axial-piston pumps) is shown in figure 11–4. In the latter illustration, you see that the RUDDER YOKE is connected to two hydraulic PLUNGERS or RAMS, each of which is equipped with CYLINDERS at both ends. The hydraulic fluid is pumped in the closed system by one of the two rotary, positive displacement, VARIABLE-STROKE PUMPS. The motors run at constant speed. The direction and rate of fluid delivery is regulated by changing the angle of the TILTING BOX in the hydraulic pump, which is in turn controlled either electrically or hydraulically from the steering wheel on deck. The CONTROL SHAFT and gearing are indicated in the illustration. Note that the forward-port and after-starboard cylinders are interconnected, and the same applies to the forward-starboard and the after-port

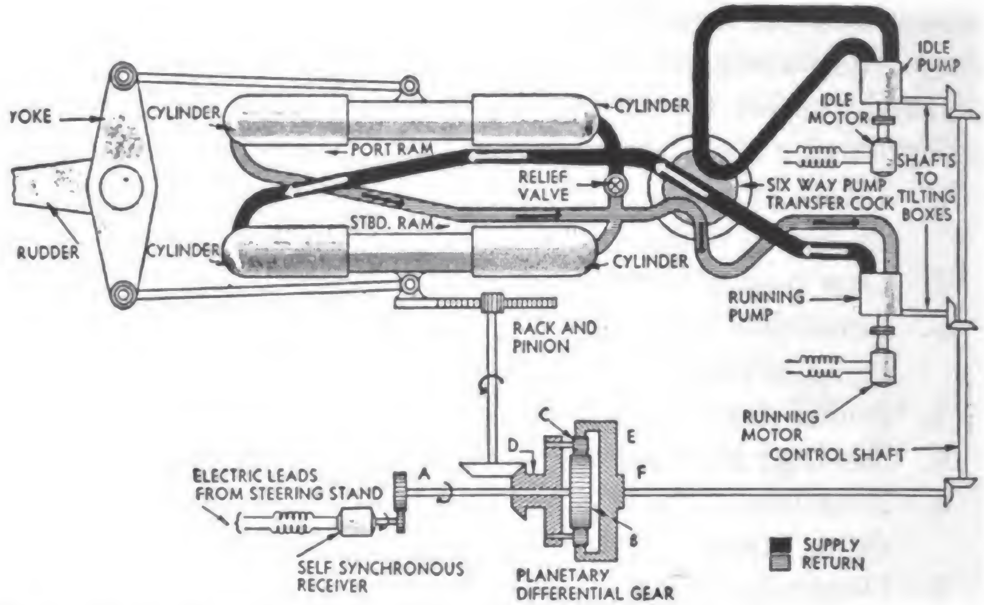


Figure 11–4.—Diagrammatic arrangement of a double-ram electrohydraulic steering gear (with axial-piston pumps).

cylinders. A double-acting RELIEF VALVE functions to bypass the fluid from the pressure line to the return (or suction) line, thus relieving the piping from excessive strain, in case an unusual resistance to the rudder results in abnormal pressure.

Starting with a neutral position of the tilting box and no flow of oil, suppose the steering wheel is turned to starboard. The SYNCHRONOUS RECEIVER will then turn correspondingly (counterclockwise in illustration, as viewed from left). Shaft *A* is turned clockwise and carries with it the gear *B*, which is secured to shaft *A*. The gear *C*, meshing with gear *B* and with an internal gear on casing *E*, turns counterclockwise. Then *E* turns counterclockwise and turns the control shaft, which operates the tilting boxes on the pumps. A quantity of oil now flows to the forward-port and after-starboard cylinders, the rams move as shown, and an equal quantity of oil is returned to the pumps from the opposite cylinders. The rudder is thereby moved to the right.

Now suppose the steering wheel and the synchronous receiver have stopped. The starboard ram, in moving forward, operates the RACK AND PINION and turns gear *D*

clockwise. Gear *B* and shaft *A* are now held by the motionless receiver, and as a result gear *C* and casing *E* turn clockwise, thus returning the tilting boxes to the neutral position and stopping the flow of oil. The PLANETARY DIFFERENTIAL GEAR, thereby, operates as a follow-up mechanism. If the steering wheel is turned to port, the actions described are the opposite in direction.

Most steering gear installations have two sets of synchronous receivers, and two sets of electric motors and pumps are provided for reliability and flexibility. The SIX-WAY PLUG COCK makes it possible to transfer quickly from the operating pumps to the standby pump.

CARE OF HYDRAULIC RAMS.—Since portions of the rams in an electrohydraulic steering gear are exposed where they fit into the cylinders, it is important that the exposed parts be protected against water. damage from rolling or falling objects, and from being used as walkways. The rams should be inspected frequently during operation. The exposed parts should be kept covered with a coat of thin-film rust-preventive compound, or heavy oil. To protect the exposed parts from rolling objects, a guard should be placed over the parts, and the steering gear compartment should be kept clear of loose gear that might slide into the rams.

If rust accumulates on the rams in spite of precautions taken, it should be removed with a wire brush—with the sliding parts of the rams covered with clean cloths. If clean cloths are not used, pieces of wire and dirt may stick to the rams and be drawn into the cylinders.

The packing followers should be tightened just enough to maintain sufficient pressure on the rings to prevent leakage. A special spanner wrench is generally provided for turning the follower. Care should be taken not to tighten the packing excessively; this results in rapid wear and improper functioning of the packing.

The oil in the high-pressure hydraulic system should be filtered about every six months. Lack of proper filtering

results in the accumulation of foreign matter which may injure the rams and the variable stroke pumps. When adding makeup oil to the system, the oil should be filtered through cheesecloth.

Anchor Windlasses

The types of windlasses which you will probably have to maintain are the electrohydraulic and the hand-driven. In maintaining a hand windlass, it is extremely important to see that the linkage, friction shoes, locking head, and brake are adjusted properly and in satisfactory operating condition at all times. In maintaining an electrohydraulic windlass, your chief concern will be the hydraulic system. Since the maintenance of all hydraulic systems is basically the same, the information given later in this chapter, under "Maintenance of Hydraulic Systems," is applicable to windlasses.

Even though used intermittently and only for relatively short periods of time, a windlass must be capable of handling the required load under extremely severe conditions. To prevent deterioration and to provide dependable operation wherever required, maintenance and adjustment must be continued during the periods when the machinery is not in use.

Windlass brakes must be maintained in satisfactory condition if they are to perform their function properly. Because of wear and compression of brake linings, the clearance between the brake drum and band will increase after a windlass has been in operation. Brake linings and clearances should be inspected frequently. Means of adjustment are provided on all windlass brakes. Adjustments should be made in accordance with manufacturers' instructions.

Lubrication instructions furnished by the manufacturer should be followed carefully. If a windlass has been idle for some time, lubrication of the equipment should be accomplished before operation is attempted. After a windlass has been used, the equipment should be lubri-

cated to protect finished surfaces from corrosion, and to prevent freezing of adjacent parts.

The hydraulic transmissions of electrohydraulic windlasses and other auxiliaries are manufactured with close tolerances between moving and stationary parts. If these tolerances are to be maintained and unnecessary wear prevented, every possible precaution must be taken to prevent the entry of dirt and other abrasive material. When the system is replenished or refilled, only clean oil should be used and the oil should be strained as it is poured into the tank. If a hydraulic transmission has been disassembled, all parts should be thoroughly cleaned before reassembly. Before piping or valves are installed, their interiors should be cleaned to remove any scale, sand, or other foreign matter.

Winches and Capstans

In several respects, the maintenance of a winch is similar to that of a windlass. Where band brakes are used on the drums, the friction linings should be inspected regularly and replaced when necessary. Steps should be taken to prevent oil or grease from accumulating on the brake drums. The operation of brake-actuating mechanisms, latches, and pawls should be checked periodically.

Winch drums driven by friction clutches should be inspected frequently to determine if deterioration has occurred in the friction material, or if oil and grease are preventing proper operation. The sliding parts of positive clutches must be properly lubricated, and the locking device on the shifting gear should be checked to determine if it will hold under load. The oil of gear reduction units should be checked for proper amount, temperature, and purity. Periodic inspections should be made of the pressure lubrication fittings normally installed on slow-moving parts. On installations which use hydraulic transmission, the pumps and lines are maintained in the same way as those of any other hydraulic system.

The terms capstans and winches, however, must not be

confused. The primary difference between a winch and a capstan is that the former has a horizontal shaft and the latter a vertical shaft.

Cranes

As with many other auxiliary units, the cranes you maintain may be driven by hydraulic transmissions, by electric motors, by Diesel engines, or by hand. Maintenance should be accomplished in accordance with manufacturers' instructions. In general, the maintenance of electrohydraulic cranes requires that the oil in the replenishing tanks be kept clean. The limit stop and other mechanical safety devices must be checked regularly for extreme positions of travel. When cranes are not in use, they should be secured in their stowed positions and all electric power to the crane controllers disconnected at the power distribution panel.

Elevators

Carriers are provided with two or more inboard elevators, capable of handling airplanes between the flight and hangar decks at relatively high speed. As an EN2, you may not be called upon too frequently to maintain this type of machinery. However, if you are required to maintain electrohydraulic elevators, you will find maintenance procedures relatively the same as for other auxiliaries which use fluid to transmit power.

Shipboard elevators may be divided into two major classes: ELECTROMECHANICAL AND ELECTROHYDRAULIC ELEVATORS.

ELECTROMECHANICAL ELEVATORS.—The platform of electromechanical elevators is raised and lowered by two groups of cables which pass over sheaves to the hoisting machinery. Two hoisting drums, coupled together, are driven through a reducing gear unit by an electric motor. The motor is of the two-speed type (full speed and one-quarter speed). Control arrangements are such that the elevator starts and runs on the motor high-speed connec-

tion, the low speed being used for deceleration as the elevator approaches the upper or lower limit of travel The platform travels on two athwartship guides. Manually operated locks equipped with electrical interlocks are provided for holding the platform in the raised position.

Freight, bomb, mine, and torpedo elevators are similar in design features to the electromechanical airplane elevator.

ELECTROHYDRAULIC ELEVATORS.—Aircraft carriers are provided with electrohydraulic elevators capable of handling airplanes between the flight and hangar decks at relatively high velocity. This class of elevators may be divided into two general types: the DIRECT PLUNGER lift and the PLUNGER-ACTUATED CABLE LIFT.

The platform of the DIRECT PLUNGER LIFT ELEVATOR is raised and lowered by direct connection with two vertical, hydraulic rams. During the hoisting operation, oil from a high-pressure tank, at a pressure of approximately 900 psi, is forced into the rams. Lowering is accomplished by discharging the oil from the rams into an exhaust tank, which is under a pressure of approximately 230 psi. Pressure in the pressure tank is maintained (at 900 psi) by means of two electrically driven variable-stroke pumps, which take suction from the exhaust tank. One of the pumps is capable of maintaining operation of the elevator at reduced speed.

Special control valves (operated either by pilot valves or by an electric motor) in the pressure and exhaust lines regulate elevator speeds by varying the amount of oil admitted to, or discharged from, the rams. Positive stops and mechanical locks, interlocked with the elevator control circuit, enable the platform to be stopped, locked, and held in position at the flight deck level. An equalizer system maintains the platform at uniform level under conditions of unequal loading. Automatic quick-closing valves in the oil line prevent the free or unrestricted fall

of the elevator. In case of damage to the main pumps, the sump pumps will generally provide sufficient power for one upward run; otherwise the emergency run is made with the reserve capacity of the pressure tank. A hand control system is provided for use when electric controls are damaged.

To provide adequate working space on the hangar deck while the elevator platform is at the flight deck level, a small auxiliary pit elevator is often provided. This elevator is raised and lowered simultaneously with the main elevator. The operating pistons receive power from the same pressure tank and discharge into the exhaust tank as used by the main elevator.

The platform of the PLUNGER-ACTUATED CABLE LIFT ELEVATOR is raised by wire-rope cables fastened to the platform at two or four symmetrically placed points. These cables, through a series of sheaves, are actuated by a horizontal hydraulic ram located beneath the hangar deck. In case one group of cables should fail, instantaneously acting safety devices engage the guide rails of the elevator in order to stop and hold the platform.

One type of plunger-actuated cable life elevator is the deck edge elevator. The deck edge elevator is cantilever supported over the side of the ship with a hinge arrangement for stowage in a vertical position. The outboard section of the platform is lifted to its stowed position by a special rigging arrangement. Vertical movement is imparted to the platform by two sets of cables attached to the inboard corners. These cables are actuated in a manner similar to that employed by the inboard elevators described previously.

MAINTENANCE OF ELEVATORS.—Frequent inspections should be made of the elevator cables and fittings, and equal tension of the individual cables in each group maintained. Frequent inspections must be made to ensure that (1) there is proper oil level in the pressure and exhaust tanks, (2) there is no excessive leakage in the sump

leak-off connections, (3) the pistons seal properly in the hydraulic cylinders, and (4) the entire system is clean.

Piping, Fittings, and Seals

In general, the piping, fittings, and seals used in hydraulic systems are essentially the same as those used in other systems containing fluids under pressure. However, in connection with the operation, care, and maintenance of piping and seals in hydraulic systems, special consideration and precautions are necessary because of the high pressures involved and the close clearances in the pumping units, rams, and other moving parts.

This section deals primarily with pipes and tubes used for conveying fluids under pressure, and with the various devices employed to join the units of the hydraulic systems. Additional information concerning the maintenance of hydraulic systems can be obtained from the manufacturer's instruction book for the specific installation.

PIPING AND TUBING.—The demands that a hydraulic system must satisfy are often varied and complex, so that various types of pipes, tubes, and fittings must enter into consideration in designing an installation. The material used depends upon several factors, such as operating temperature, and pressure.

On board ship, where piping is used for fresh and salt water, oil, compressed air, and refrigerating gases, practically all pipes and tubes are made of steel, copper, or brass.

Steel piping is relatively inexpensive, and used extensively aboard ship because of its strength, its suitability for bending and flanging, and its adaptability to high pressures and temperatures. The chief disadvantage of steel piping is its comparatively low resistance to corrosion.

Copper piping and tubing are sometimes used on high-pressure lines, or where operating temperatures are below 350° F. Copper is unsatisfactory for high tempera-

tures, or if subjected to repeated stresses, because it has a tendency to harden and break under these conditions. (At 360° F, the resisting strength of a copper tube is reduced about 15 percent.) However, it should be noted that copper can easily be drawn out or bent.

Brass piping instead of copper is sometimes used where the maximum working pressure is less than 250 psi. Brass is very resistant to corrosion, but cannot be bent as easily as copper. Brass piping is usually employed in low-pressure systems, as in drain or lubricating lines.

The units of a hydraulic system are designed as compactly as practicable in order to keep the connecting lines short. Every section of piping is anchored securely in one or more places so that neither the weight of the piping nor the effects of vibration is carried on the joints.

It often becomes necessary to introduce bends in the piping of a hydraulic system in order to reduce the number of joints or avoid obstructions that would otherwise require the use of several pieces of pipe and fittings. The best radius for a pipe bend is between 2.5 and 3.0 times the inside pipe diameter, as shown in figure 11–5. If the inside diameter of a pipe is 2 inches, the radius of the pipe bend should be between 5 and 6 inches.

FITTINGS FOR PIPING SYSTEMS.—The pipe fittings most commonly used in hydraulic systems are either flanged

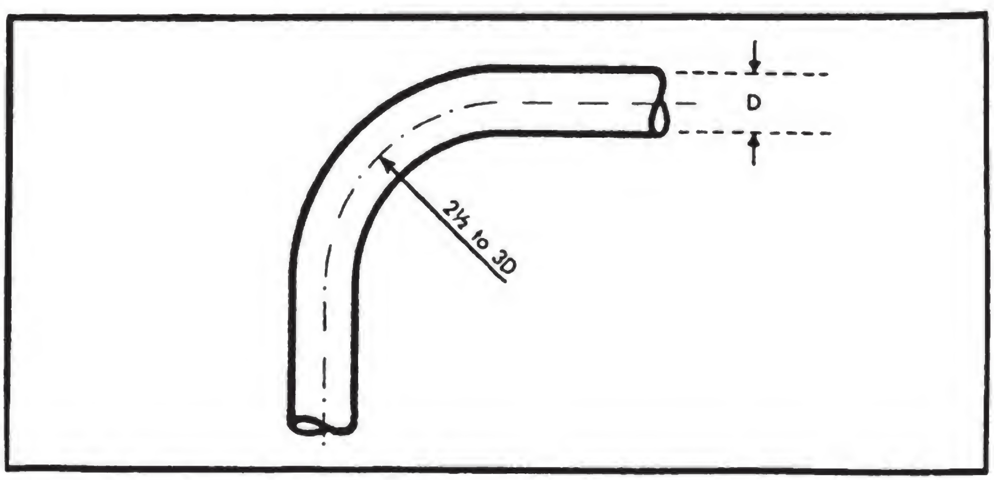


Figure 11–5.—Radius of pipe bend.

or of the compression types. However, a new type of tube fitting referred to as a compression BITE type, with a straight thread, will be installed on naval ships in the near future.

As far as other piping systems are concerned, screwed, flanged, and compression fittings are used. The information on flanges and compression fittings, given in the paragraphs which follow, is applicable to hydraulic and other piping systems.

SCREWED FITTINGS are commonly employed in low-pressure pipes such as lubricating or drain lines. In Navy systems, they are usually made of steel, copper, or brass, and in a variety of designs (fig. 11–6). Screwed fittings are made with standard female threading—threading cut on the inside surface—and require that the end of the pipe be threaded with outside male threads for connecting.

The threads should be cut clean and smooth. The dies and pipe cutting tools should be sharp so that they will not drag metal; otherwise the threads will fit poorly, and

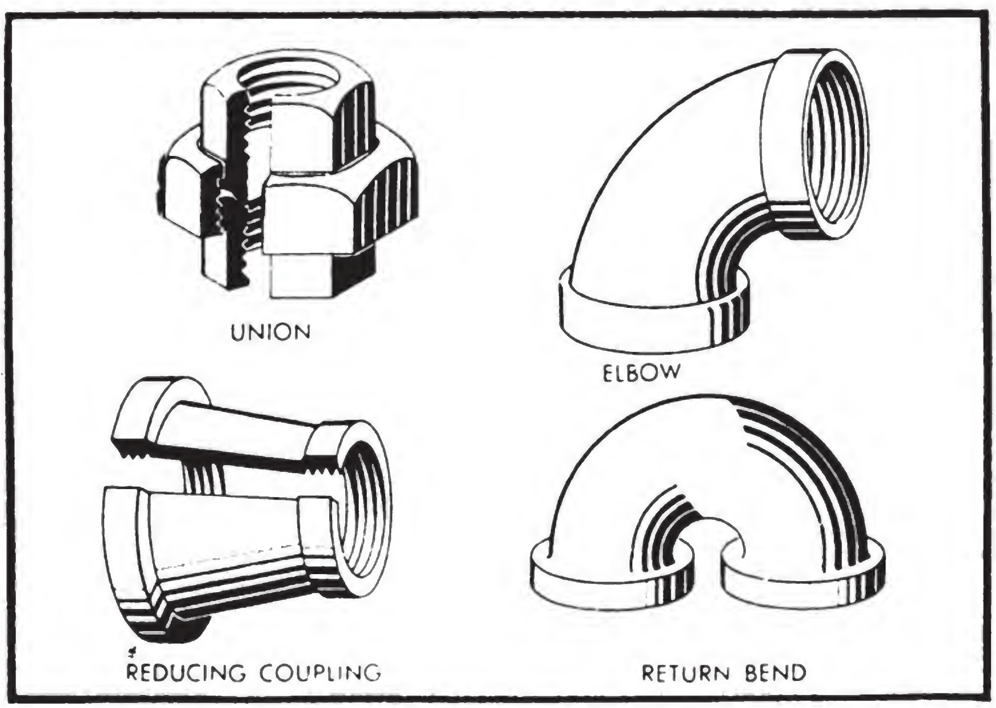


Figure 11–6.—Screwed fittings.

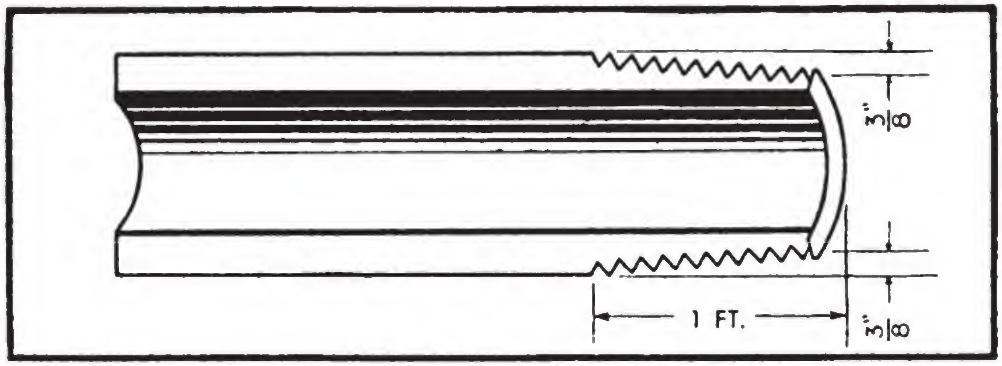


Figure 11–7.—Tapering of standard pipe threads.

leakage may result. When cutting threads, use oil liberally. Standard pipe threads are tapered slightly to ensure tight connections. The amount of taper is about 3/4 inch in diameter per foot of thread (fig. 11–7).

After the pipe has been cut or threaded, the ends should be inspected for burrs. All projections and sharp edges should be removed (fig. 11–8). If this is not done the flow of liquid will be obstructed. In addition, loose particles of metal may get into the pipeline and damage the system.

Metal is removed when a pipe is threaded, thinning the pipe and exposing new and rough surfaces for chemical

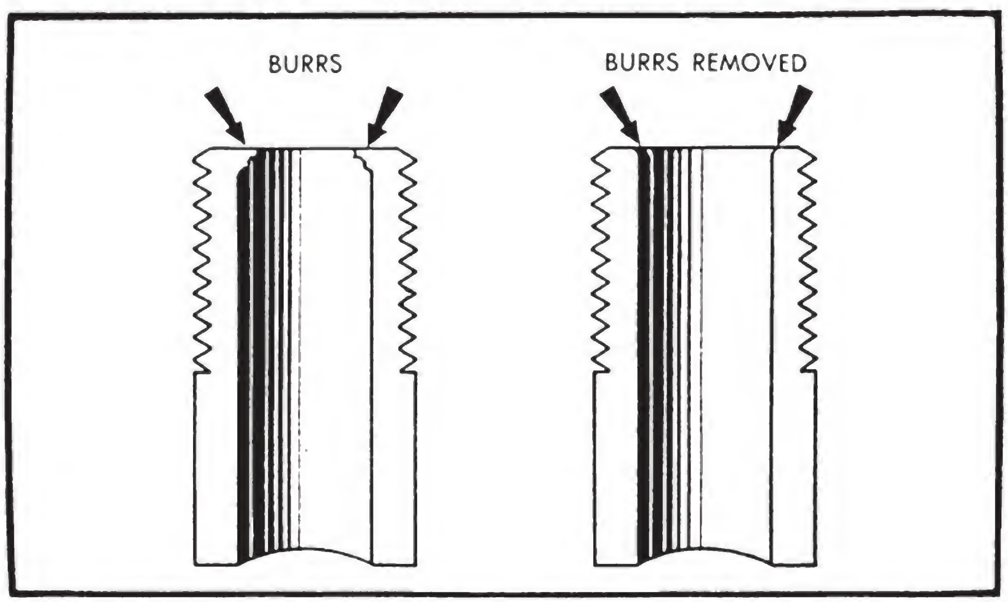


Figure 11–8.—Removal of burrs.

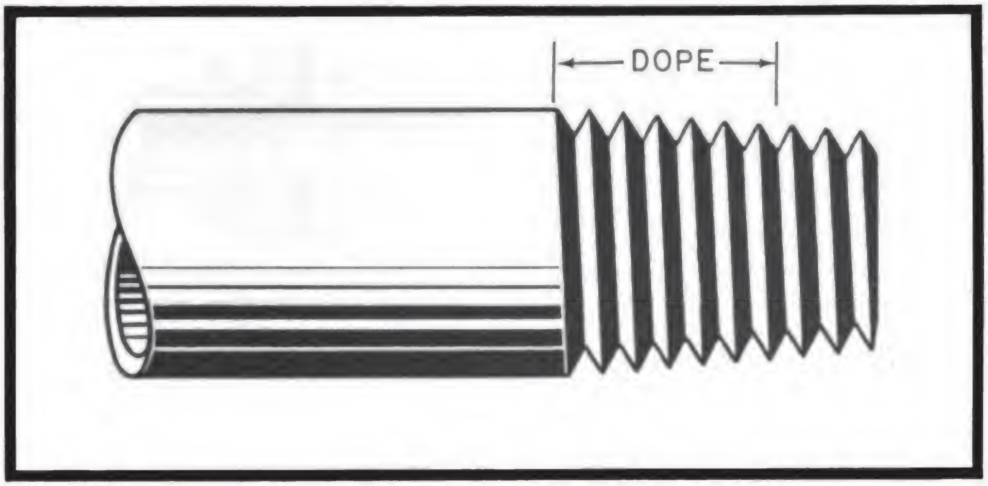


Figure 11–9.—Use of "pipe dope."

action. Corrosive agents work more quickly at such points than elsewhere. If pipes are assembled with no protective compound on the threads, corrosion sets in at once and the two sections stick together so that the threads seize when disassembly is attempted. The result is damaged threads and pipes.

To prevent seizing, permatex or a similar "pipe dope" should be placed on the threaded portion of the pipe, down to about the third thread from the end (fig. 11–9). The antiseize compound should not be placed at the extreme end of the threading, as some particles may loosen into the pipeline and cause unnecessary damage to the system. The antiseize compound should be placed on male fittings only, so that the screwing process will not push the compound into the system. To assure a good fit free from leakage, at least two-thirds of the threaded portion of the pipe should be screwed into the fitting. (The connection should be made tight with a wrench.)

FLANGES are generally used on high-pressure lines and large-diameter pipes. (The FLANGED FITTINGS used on hydraulic tubing are identical with flanged pipe fittings.) The most common type consists of two cast or forged flanges (fig. 11–10A), secured to the pipe ends and bolted together as shown in figure 11–10B. In order to make

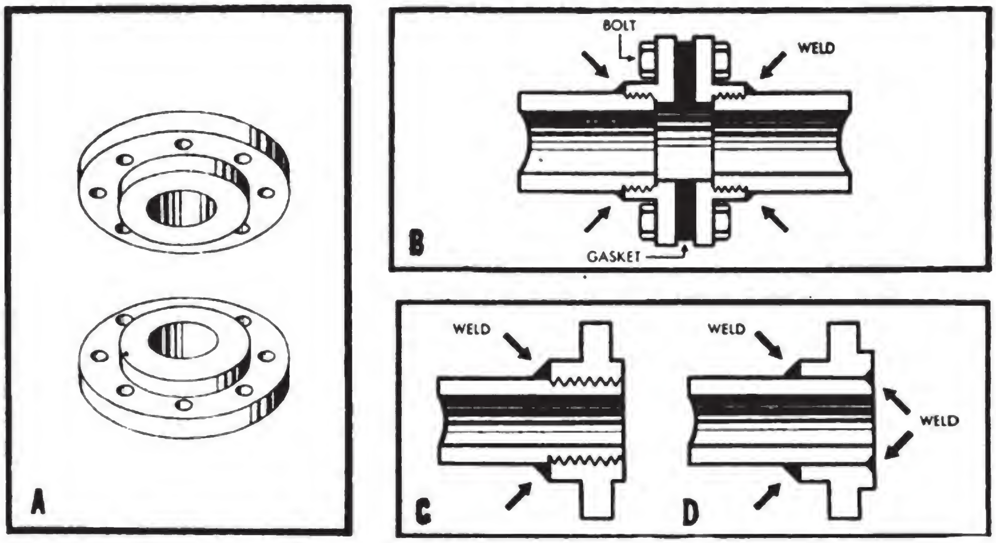


Figure 11–10.—Flanged fittings.

a tighter connection, a gasket is placed between the meeting faces of flanges.

In hydraulic installations, flanges are either screwed to the threaded end of the pipe and backwelded (fig. 11–10C), or they are slipped over the end of the pipe, welded front and back, and then refaced flush with the pipe end (fig. 11–10D). The welding eliminates any possibility of leakage between the flange and the pipe.

To secure a tight joint, the joining surfaces of flanges can be faced in many ways. Figure 11–11 shows three of the most common types of faces used in hydraulic installations.

Flanges with PLAIN RAISED FACES have a machine-ground surface, and may be used with either a square or ring gasket. With this type of joint the flanges must meet perfectly. Compared with other types of flange faces, the advantages of the plain raised face type flange are: (1) the mating of flanges is eliminated, (2) the gasket is easy to center, and (3) a section of piping fitted with this kind of flange can easily be removed without springing the line apart.

The MALE AND FEMALE type of flange has a cutaway (female) area on the face of one flange and a correspond-

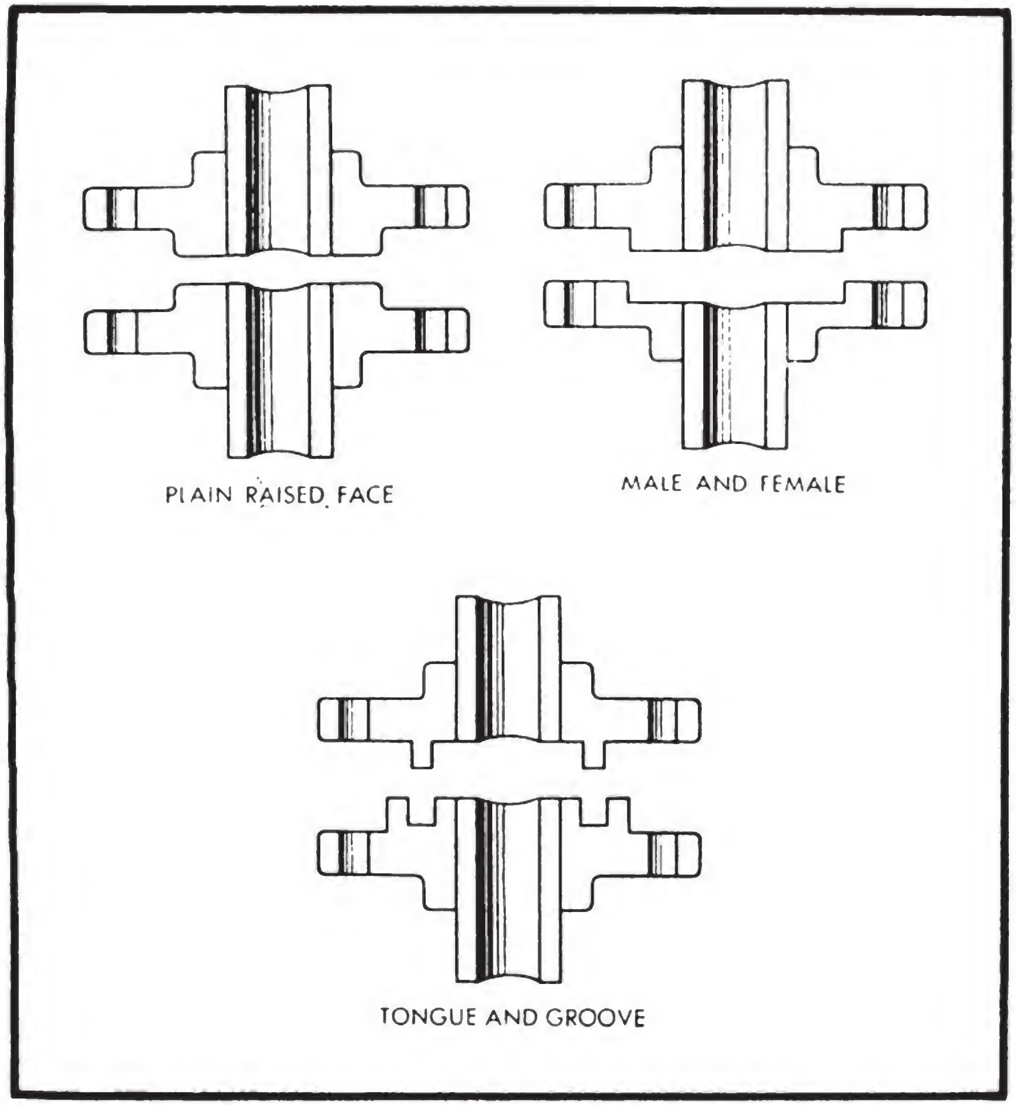


Figure 11–11.—Types of flange faces.

ing raised (male) area on the face of its mate. This type of flange normally requires a small ring gasket. This makes a more secure joint than the plain raised-face type. The tongue and groove type of face has a raised ring on one flange and a corresponding ringed groove, or cutaway area, on the other flange.

As far as maintenance is concerned, flanges that must be mated are undesirable because interconnected units have to be sprung apart in order to be removed from the line. They are used, however, in high-pressure installa-

tions, where the plain raised-face type does not make a satisfactory connection.

Flanged joints are usually bolted together securely by four bolts. The flanges must line up squarely. When being assembled, bolts diametrically opposite should be set up fairly tight. Then the other two bolts should be set up an equal amount. The bolts should then be taken in order, setting up each one an equal amount, until they are equally tight.

COMPRESSION FITTINGS.—In medium- or low-pressure tube lines, compression fittings are used. Figure 11–12A illustrates the Bell type compression fitting which consists of a tube nut and a tube coupling so threaded that the coupling screws down over the nut. The nut is fitted over the tube, and the end of the tube is flared. The nut and the flared tube end are then fitted into the female opening of the tube coupling. As the tube nut is tightened, the flared end of the tube is compressed against a machined taper in the tube coupling, providing a firm connection.

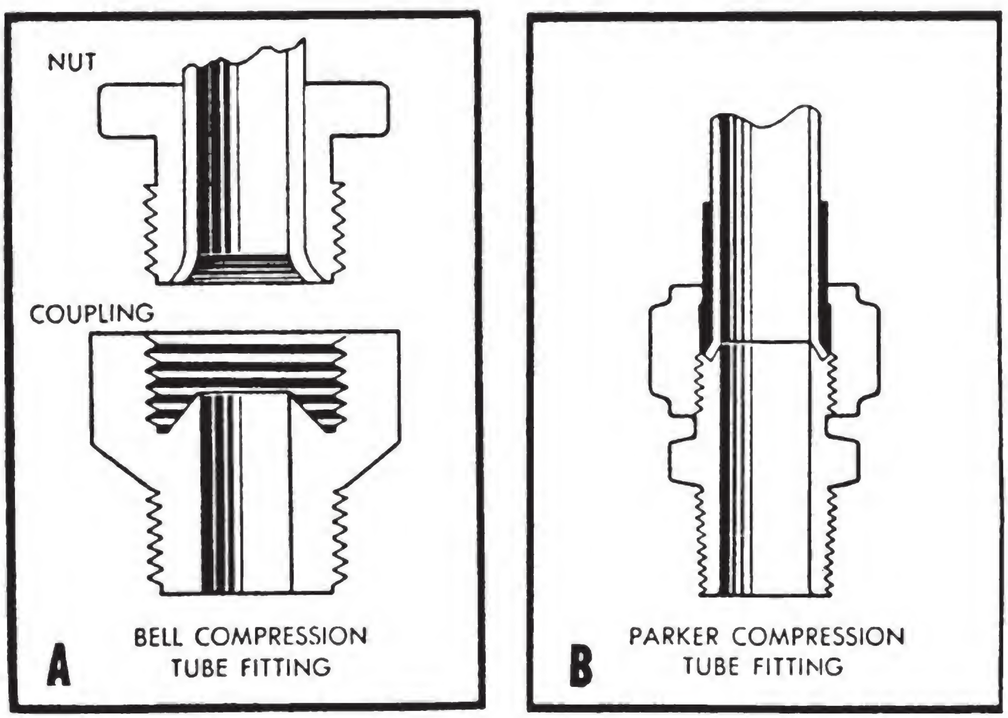


Figure 11–12.—Compression fittings.

The Parker triple-compression fitting is similar to the Bell type fitting, except that a sleeve is placed between the flared tube and the nut, as shown in figure 11–12B. The sleeve protects the flare from strain as the nut is tightened, since the nut turns against the shoulder of the sleeve instead of directly against the flare.

When the tube is properly flared and the tube nut tightened, the flare will seat itself firmly in the machined recess of the tube coupling. The tube will not turn relative to the coupling when the nut is tightened, and the flare will assume the shape of the machined surface. Any irregularities in the machined recess will be taken up by the tube flare, making a leak-proof connection. However, if the original connection is broken and the compression tube fitting must be reassembled, it is not likely that the flare will contact the machined recess in the original places. In that case, it is necessary to anneal or soften the flared end of the tube prior to reassembly.

Copper can be annealed by heating it to a red heat and then quickly quenching it in cold water. This process will soften the copper sufficiently to allow it to assume the shape of the coupling surface when the tube nut is tightened.

When compression fittings are used with steel tubing, a thin copper gasket is placed as a seal between the tube flare and the machined recess. This copper gasket must then be softened before reuse.

GASKETS, PACKING RINGS, AND OIL SEALS.—Gaskets made of relatively soft materials are placed between the meeting surfaces of hydraulic fittings in order to increase the tightness of the seal. The gaskets should consist of materials that will not be affected by the liquid to be enclosed, and by the conditions under which the system operates, including maximum pressure and temperature.

NEOPRENE GASKETS AND PACKING RINGS.—The selection of correct seals and their proper installation are

important factors to consider in maintaining an efficient hydraulic system. In making gaskets for hydraulic systems, one of the materials widely used is neoprene. This material comes in sheet form which is used between flat surfaces, and in molded packing rings used around movable rods and shafts. Since neoprene ~~is~~ flexible, it is often used in sheet form at points where a gasket must expand sufficiently to allow air to accumulate.

Since oil tends to deteriorate neoprene gasket material, the condition of neoprene gaskets should be checked whenever a unit is disassembled. In handling neoprene, extreme care is also necessary because it easily becomes scratched or torn. (Neoprene gasket material is soft and flexible.) Shellac, gasket sealing compounds, or "pipe dope" should NOT be used with sheet neoprene, unless absolutely necessary for satisfactory installation.

The neoprene material used for chevron packing rings (fig. 11–13) is made of a harder composition than that used for gaskets, and is molded to fit a particular stuffing box and rod. This type of ring is sometimes filled with soft neoprene strips. Under pressure, the chevron packing rings are forced together so that they spread out, causing the soft filler to expand and therefore force the feathered chevron edges more firmly against the rod. Figure 11–13

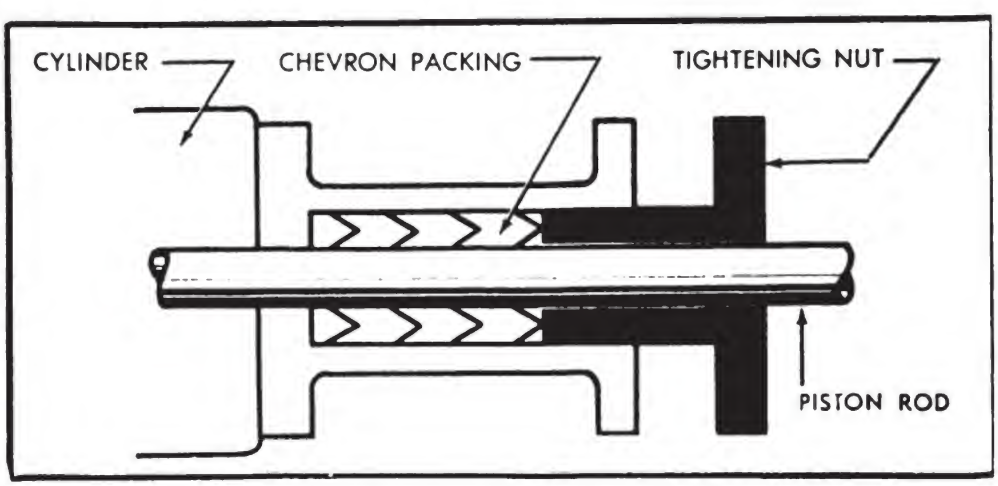


Figure 11–13.—Chevron packing.

illustrates a number of chevron packing rings in place around a piston rod.

Before installing this type of ring, it should be soaked in oil for several hours to help it assume the shape of the rod. If it is not possible to soak the packing, the tightening nut should be tightened sufficiently to prevent binding of the rings.

Until the packing becomes set, the leakage around the shaft may seem excessive. Since a small amount of leakage is unavoidable, and necessary to lubricate the rings and shaft, the tightening of the retaining element is an operation that requires extreme care. Tightening chevron packing excessively will cause unnecessary friction and scoring of the ram or piston rod.

All large diameter chevron packing rings are furnished split for easy installation and removal. When installing this packing, the joints for the individual rings should be staggered in the gland in order to minimize leakage through these joints.

When disassembling a hydraulic unit where this type of packing ring must be removed over a threaded shaft or rod, the threads should be covered with a thin piece of sheet brass, or a cap generally provided for this purpose, in order that the threads will not damage the interior of the packing ring.

OIL-TREATED PAPER.—Gasket paper usually comes in sheets, and the gasket for each particular installation must be cut. Before cutting, the paper should be marked to size. It should not be placed on the valve plate or other surfaces, or tapped with a ball peen hammer; this causes burrs.

Sheets of gasket paper vary in thickness from several thousandths of an inch to almost any desired thickness. A thick gasket is not always the best. For example, when a gasket is installed between a valve plate and the valve block, the thickness may determine the clearance of working parts.

When oil-treated paper gaskets are torn, wrinkled, or bent, leaky connections may result. If gasket shellac or cement is used, it should be applied to one side only so that the gasket will not be torn when the unit is disassembled.

LEAD FOIL.—In some high-pressure connections, with only slight clearance (0.001 to 0.005 inch), lead foil is used as gasket material. When disassembling a unit where lead foil gaskets have been used, extreme care should be taken not to bend or tear the foil if it is to be used again.

CORK.—This material makes a good oil seal and can be used under various pressure conditions. Cork is very compressible and can be cut to any desired thickness to fit any surface. When a unit is disassembled, the conditions of cork gaskets should be checked for defects.

COPPER.—This material is used in hydraulic systems, both in the form of flat copper rings (used under adjusting screws, to give oil seals), and as molded copper rings used with speed gears, operating under high pressures.

Care of Hydraulic Systems

Regular operation, proper lubrication, proper maintenance of all the units, and cleanliness of the fluid are principal requirements for keeping a hydraulic transmission in satisfactory operating condition. Regular operation of hydraulic equipment prevents corrosion, sludge accumulation, and freezing of adjacent parts. The need for proper lubrication and cleanliness cannot be too strongly emphasized.

Detailed instructions concerning the maintenance of a specific unit may be obtained from the appropriate instruction book; however, the general information which follows will also be helpful.

CORROSION OF VARIABLE-SPEED GEARS.—The hydraulic variable-speed gears should be kept full of oil at all times, to guard against corrosion. Otherwise, moisture may enter the case through the air vent on the expansion box

and condense, thereby causing rust which may eventually jam the working parts. Occasional inspection is necessary, however, to ensure proper oil level. Except for small globe valves, the repair of gears is generally accomplished in a Navy yard or by the manufacturer.

AIR IN SYSTEM.—Every cavity of the system must be filled with oil to exclude all air. When filling the system, vent plugs at the high points should be left open until all the air escapes then closed to avoid waste of oil.

Before the system is started under power, it is well for the gears to be turned over slowly to work the air out of the system. Otherwise, the air is likely to be whipped up into small bubbles which would escape very slowly. Hand-turning should continue as long as any air bubbles are seen escaping in the expansion box or at any of the bleeder plugs.

BUILT-IN SYSTEM FILTERS OR STRAINERS.—Hydraulic systems often include built-in filters or strainers. Filters are located in the high- or low-pressure piping, while strainers are generally located at the end of the oil suction line, in the oil reservoir. These devices should be changed when it is determined that they are no longer cleanable.

DIESEL EMERGENCY GENERATORS

Practically all naval vessels are equipped with Diesel-driven emergency generators. (Diesel engines are most suitable for this application because of their self-sufficiency and quick-starting ability.) Emergency generators furnish power directly to the electrical auxiliaries, radio, radar, gunnery, vital machinery spaces, and other spaces. In addition, emergency generators serve as a source of power for casualty power installations.

The typical shipboard plant consists of two Diesel emergency generators, one forward and one aft, in spaces outside the enginerooms and firerooms. Each emergency generator has its individual switchboard and switching arrangement for control of the generator and for distri-

bution of power to certain vital auxiliaries and to a minimum number of lighting fixtures in vital spaces.

The capacity of the emergency unit varies in accordance with the size of the vessel on which it is installed. Regardless of the size of the installation, the principle of operation is the same.

Diesel engines are started either by compressed air or by a small d-c motor driven by storage batteries. The engines are designed to develop full rated load power within 10 seconds.

In a typical installation, the starting mechanism is actuated when the ship's supply voltage on the bus falls to about 80% of normal. In a 440-volt system, this would be about 350 volts. The generators are not designed for parallel operation. Therefore, when the ship's supply voltage fails, a transfer switch automatically throws the load from the main distribution switchboard to the emergency switchboard.

When the ship's supply voltage is restored and the voltage reaches a predetermined value—say approximately 92% of normal—the automatic transfer switch throws the load back to the main distribution switchboard. After this occurs, the engine must be stopped by hand and manually reset for automatic starting.

Since the Diesel emergency generators are of limited capacity, only certain circuits can be supplied from the emergency bus. These include such circuits as the steering gear and the interior communication switchboard. If some vital circuit is secured, another circuit may then be cut in, up to the capacity of the generator.

Since the emergency system is important, you should become familiar with the system aboard your ship.

Operating Instructions

If you are assigned to operate and maintain Diesel emergency generators, you must be familiar with the operating instructions and maintenance procedures for the complete installation. The instructions which follow

are applicable to most of the air-started type engines. In addition, you should know the location of the remote shutdown station and how to secure the engine from there. (All Diesel-powered emergency generators have remote shutdown devices.)

The engine is started automatically when the ship's supply current fails and causes the solenoid air valve (located between the starting air tank and the engine) to open, admitting starting air to the engine. The engine then turns over on air until firing begins. As the engine speed increases, the air cutoff governor valve closes and shuts off the starting air. As soon as the normal operating speed is reached and the generator develops normal voltage, the solenoid air valve also closes to shut off the starting air supply. (The starting air tank is charged from the high-pressure air system, through a reducing valve. The pressure carried in the starting air tanks varies from 300 to 600 psi, depending upon the installation.)

To start the engine manually, the solenoid valve must be de-energized. In case the ship's current is not broken, it is necessary to open the switch in the solenoid circuit. Starting air can then be admitted to the engine by opening the valve manually with the handwheel. After firing begins, the handwheel should be turned to close the valve and cut off the starting air. (The handwheel must be turned to the open position of the valve whenever it is desired to leave the generator set available for emergency service.)

If the lubricating oil pressure does not build up immediately after the engine starts, shut down the engine and determine the cause of the trouble. Never operate the engine without lubricating oil pressure. At regular intervals, the lube oil pressure, the fuel pressure, the cooling water temperature, and the exhaust temperature should be checked. (In addition the fuel and lubricating filters should be cleaned regularly.)

To SHUT DOWN the engine, hold the fuel-control lever in the STOP position. After the lever is released, it automatically returns to the running position in order to permit the engine to be restarted.

Immediately after the engine is shut down, the crankshaft should be turned a few revolutions on air only so that all the starting gear will be in order for the next emergency start. This blows out any accumulated lubricating oil from the starting air distributor while it is warm, and facilitates starting.

To ensure prompt emergency starting, after the engine has been idle, the vent valve on the high-pressure fuel pump should be opened and a small amount of oil allowed to flood through.

Remember that some fuels have a tendency to stick the overspeed safety stop valve stem in the valve body. To ensure proper operating conditions and to make certain that the stop valve is free, this valve should be worked in and out several times after the engine is shut down. The valve stem should be pushed in and latched in the running position, otherwise the engine cannot be started.

Operating Precautions

The following operating precautions must be observed:

1. Do not operate the engine without lubricating oil pressure; this may result in lack of lubrication and cause serious damage.
2. Do not operate the engine in overloaded condition. Overload condition on one or more cylinders may be indicated by an increase in the exhaust temperature or smoky exhaust.
3. Do not operate the engine with an abnormal water outlet temperature. (The recommended water outlet temperature is 155° F.)
4. Do not operate the engine after an unusual noise develops; this might be an indication of pending trouble. The trouble should be investigated and

corrected, particularly if it will prove harmful to the engine.

5. If there is danger of freezing, during shutdown periods, drain all water jackets.
6. If the engine was shut down by tripping the overspeed stop, investigate the cause of the trouble before restarting the engine.
7. Make certain that the fittings of the ventilation system, serving the compartment in which the engine is located, are open. (If the Diesel engine were started while the vent system was secured, the engine would exhaust the air out of the compartment thereby suffocating the operator as well as the engine. This applies to installations where the engine does not have a direct air supply, from the outside, to the intake manifold.) It is important to note that these precautions are also applicable to emergency Diesel fire pumps.

Periodic Tests of Emergency Generators

The following tests should be performed:

1. Jack over the engine daily, by means of the jacking bar. (Some engines are provided with an air-driven jacking motor.)
2. Run the engine, by power, once each week.
3. Test the overspeed trip by overspeeding the engine and noting the rpm at which the device trips; this test is performed when the engine is run once each week (No. 2 above).
4. Test the Diesel emergency generators at full rated load and voltage for at least 12 hours, once each month.

Maintenance of Equipment

The engine should be given special care for the first 200 hours of operation. (In addition, inspections at the end of 800–1000 hours operation, as well as 2400–3000 hours, and 4000–5000 hours should be made in accordance

with manufacturer's instructions.) Watch all indications of unusual temperatures and pressures. Check the equipment for loose nuts, and examine the adjusting devices. At the end of the 200 hour period, remove the crankcase doors and retighten all bolts, nuts, and studs. Detailed information concerning the various inspections, as well as inspection schedules, may be obtained from the manufacturer's instruction book.

However, as far as maintenance of the equipment is concerned, the important factors will be discussed in the paragraphs which follow.

COOLING SYSTEM.—When inspecting the cooling system, the following checks should be made:

1. See that the bearings of the circulating pump are properly lubricated. Bearings are filled with the proper amount of grease at the factory. However, if leakage occurs, or after the system is overhauled, additional grease will be required.
2. See that the stuffing box is well packed, but not too tight. The packing is water lubricated and a slight leakage of one or two drops a minute is desirable to indicate that it is receiving lubrication. The packing should be cut into lengths to go around the shaft once, and all joints should be staggered.
3. If there is danger of the cooling system freezing up during shutdown periods, drain the entire system. (There is a drain valve on the exhaust side for draining the engine jackets, and pipe plugs in the water pump, oil cooler, and exhaust manifold for draining these units.)
4. Do not tamper with the thermostatic element of the water temperature regulator. Since there are no adjustments for this unit, the thermostatic element (which includes the piping and bellows) should be replaced when it fails to function. (The regulator spring has an adjustment for changing its tension and thereby the water outlet temperature, but inasmuch as this adjustment is correctly made at the fac-

tory, there should be no further adjustment necessary unless replacement parts have been installed.)

5. Clean the fresh water cooler only when there is an abnormal increase in pressure drop, or a decrease in efficiency. (To clean the cooler, remove the unit from service and immerse it in a suitable solvent. To simplify cleaning operations, the covers may be removed and the core withdrawn, if desired.) After cleaning, reassemble the unit, and use new gaskets, if necessary. The zinc electrodes should be examined every 30 days and replaced when necessary.
6. Inspect the water jackets for the presence of sediment or loose scale. (When inspecting the water jacket surfaces, inspection covers and plugs should first be removed from all cylinders and cylinder heads.) Complete prevention of scale formation is not possible, however, steps should be taken to reduce its formation. Proper cleaning methods and procedures must be followed. Sea water discharge temperature should be maintained below a specified limit (130° F), because the rate of scale formation is increased as the temperature increases. The water used in closed cooling systems must be as pure as possible. Distilled water is recommended for a fresh-water cooling system, but since distilled water is not absolutely pure water, additional steps must be taken to control acidity and alkalinity. The treatment used to control these factors will not remove scale already formed, but it does prevent further precipitation of scale-forming salts. Details for water treatment in closed water systems is given in chapter 41 (section II, part 10) of BuShips *Manual*, and in most engine instruction manuals.

LUBRICATING SYSTEM.—The following maintenance factors concerning the lubricating system should not be overlooked:

1. Adjust the stuffing box packing of the oil pump, when necessary.
2. Do not operate the engine without lubricating oil pressure; this may result in lack of lubrication, and cause serious damage.

Loss of lubricating oil pressure can be caused by various reasons, and some of them are listed below in the most probable order in which they will occur.

Dirty filter.

Check valve in suction line stuck or clogged.

Insufficient oil in system.

Improper adjustment of the pressure-regulating valve.

Pressure-regulating valve held open by foreign matter.

Leaky joints in pump suction line.

Loose or broken connections in the distributing system.

Excessive clearance in bearings, permitting oil to escape too freely. This condition should be audible by the engine knocking excessively when operating.

Leak in the lube oil cooler. This is evidenced by oil in the cooling water discharge.

AIR STARTING SYSTEM.—Maintenance of the SOLENOID AIR VALVE will be primarily at the diaphragm which should have a periodic test inspection, and the return spring which may become weak from fatigue. The main poppet valve should be reground, if necessary. Under no circumstances should the two air vent holes be plugged or restricted because they are essential to valve operation.

The STARTING AIR DISTRIBUTOR requires practically no maintenance because lubrication is provided from the engine system and the starting air is clean. However, if the distributor is removed from the engine, match marks should be made on the body and flange, and on the rotor and camshaft, to ensure proper reassembly and timing.

The air starter is timed to admit starting air between

dead center and 5° past on the power stroke. To check the timing, disconnect the distributor lines leading to the power cylinders then bar the engine over slowly in the direction of rotation. With the quick-opening valve held open, note the position of the crankshaft when the air distributor valve begins to open. This will be indicated by the escape of air through the openings which connect to the power cylinder. In case the air starter opens too soon or too late, the position of the opening can be altered by loosening the flange, which secures the distributor body to the engine, and by rotating the body a few degrees, as required. Rotating the body in the direction of rotation of the camshaft will retard the opening, and rotating it in the opposite direction will advance the opening. When the proper setting is obtained, tighten the flange securely. (Before altering the timing, it is best to prick-punch or chisel marks on the body and flange to indicate the original setting.)

Since the main air starting valve is normally closed and operates only when starting the engine, there is practically no wear, and maintenance consists mainly of inspection and cleaning.

If there is no moisture or oil in the starting air, a gummy deposit may form on the inner surfaces between the balance piston and valve. When running, the lower part of the valve, exposed to combustion gases, gets warm and bakes this gum into a scale which in time may build up sufficiently to partially stick the balance piston.

This scale also cracks off and is sometimes caught between the valve and its seat, particularly when starting. This causes the combustion gases to enter the air starting manifold, and if the mechanism is permitted to operate for more than a few minutes, it will heat up and burn paint from the manifold. If it is necessary to keep the engine running, fuel should be shut off from this particular cylinder. To free the valve, it will be necessary to remove the cage and piston. Twisting and tapping the valve at the stem end will usually work it closed. At the

same time, if a small amount of kerosene or penetrating oil is applied, the valve will be clean and free.

In disassembling the valve, it has to be removed from the bottom of the head, but the balance piston and rings should be removed from the top of the head, otherwise the rings will foul in the air passage and probably break. Therefore, the rings should also be replaced from the top. It is best to assemble the valve with the balanced piston, the rings, the spacer, and the nut on the outside to check the rings in their grooves. Do NOT spring rings over the piston, as this will distort them.

FUEL SYSTEM.—If the FUEL SERVICE TANK has just been installed or drained, it should be filled manually before making the initial start. The plugged opening on top of the tank may be used as a filler opening. In addition, the fuel line to the fuel pump should be vented of air before starting up for the first time. (The fuel service tank should be elevated several feet above the fuel pressure pump inlet in order to allow the pump to fill during starting, until the transfer pump builds up the fuel pressure.)

The FILTER, located between the engine service tank and fuel transfer pump, is a two-stage unit. The first stage element is a metal edge unit having 0.001-inch spacing and the second stage is an absorbent type element good for a minimum period of 500 hours operation on oil containing 0.005 percent of filterable solids. The metal edge element can be cleaned by removing and washing it in solvent. The absorbent element, however, cannot be cleaned and should be replaced when necessary.

The FUEL OIL FILTER (PUROLATOR), located between the service tank and the engine, is a two-stage metal edge unit. This filter is intended to be used only temporarily after the engine is first installed. It should be removed after approximately 200 hours operation, or after sufficient time has elapsed to ensure that all foreign matter has been removed from the system. (This also applies to the lube oil filter attached to the engine.) The filter can be cleaned by rotating the handle, without shutting

down the engine. This filter has a manual valve by means of which it can be disconnected from the system so that the element can be removed and the bowl drained. The manual valve must not be used to bypass fuel around the filter while the engine is running.

The OVERSPEED TRIP consists of a spring-loaded port type valve, located in the high-pressure fuel system. In case of overspeed, a spring-loaded bolt in the flywheel trips the valve and causes it to close and shut off the fuel to the engine. The safety stop should require practically no maintenance other than to be periodically tested by overspeeding the engine temporarily and tripping the valve. There is an adjustment of the spring bolt in the flywheel for changing the speed at which the device trips, but this adjustment is correctly made at the factory and should not be altered.

If the engine is shut down by this device, it will be necessary to cock the mechanism manually before the engine can be started. However, the cause of overspeeding should first be investigated and corrected.

The HIGH-PRESSURE FUEL PUMP and PRESSURE REGULATOR, which is built integral with the pump, require very little maintenance, provided that dirt and foreign matter are kept out of the fuel. Such material will interfere with the operation of close-fitting parts such as lapped plungers and valves. Detailed instructions for the care and adjustment of valves and pumps may be obtained from the manufacturers' instruction books.

SPEED REGULATOR GOVERNOR.—In addition to the above maintenance factors, you will probably be concerned with the care of the speed-regulating governor. The oil level should be kept high enough so that it can be seen in the gage glass on front of the governor. (A filler cup is provided in the governor cover.) The oil must be clean and new, and the container used for filling must be clean. The regular engine oil is suitable providing it is of SAE20 or 30 grade.

There are only two adjustments of the governor; the

speed and compensation adjustments. Once the engine has been placed in operation, it should not be necessary to alter the adjustments. The setting of the speed adjustment determines the engine speed. The knob should be turned to give the rated engine speed, after which it should not be tampered with.

Although the compensation adjustment is made at the factory, it should be checked when the engine is first put into service. To check the adjustment, proceed as follows:

1. Loosen the nut, holding the compensation adjusting pointer, and set the pointer at its extreme downward position.
2. Remove the compensating screw plug and open the compensating screw two or three turns.
3. Start the engine and let it hunt for about 30 seconds.
4. Close the needle valve gradually, until hunting stops, or until it is only about 1/8 turn open.
5. If the hunting does not stop, open the needle valve to about one turn and raise the compensation adjusting pointer about two graduations.
6. Close the needle valve gradually, as in step 4 above, until hunting stops. It is desirable to have as little compensation as possible. If the needle valve is closed farther than necessary, the governor will be slow in returning to normal speed, after a load change. Excessive dashpot plunger travel caused by adjusting the compensation adjusting pointer too far toward maximum position will, upon load change, result in excessive speed change.

SUMMARY

As far as compressed air plants are concerned, maintenance is of paramount importance. Even when rigid procedures are followed, a reduction in plant capacity may result from several causes. The EN2 should be thoroughly familiar with the troubles which may occur, their causes, and the corrective action to be taken. It is

not only necessary to have a thorough knowledge of written instructions, but also practical experience in maintaining all the components of a compressed air plant. This should include the care of air intakes and filters; the maintenance and repair of air valves, and of compressor air cylinders, pistons, and wrist pins; the adjustment of bearings and couplings; and the proper maintenance of the various systems in the plant.

Because of the wide application of hydraulics throughout modern Navy vessels, it is important that those responsible for care and maintenance be thoroughly familiar with machinery using this method of power transmission. In many cases, the EN2 may be required to maintain auxiliary machinery equipped with a hydraulic system. Such equipment can usually be maintained in satisfactory operating condition by regular operation, by adequate and proper lubrication, and by maintaining all units, as well as the working fluid, in the required state of cleanliness.

Personnel charged with the operation of Diesel emergency generators should be thoroughly familiar with the installations. Satisfactory operation of the emergency generator depends on the proper care and carrying out of maintenance procedures prescribed in the manufacturers' instruction book.

QUIZ

1. Why should gasoline or kerosene never be used to clean the air intake filter of an air compressor?
2. What difficulty may exist if the intercooler pressure of an air compressor drops below normal?
3. Dirt which causes compressor air valves to operate improperly can usually be traced to what three sources?
4. When inserting compressor air valves in a cylinder, what precaution must be taken?
5. What can be used as a seal against leakage at the threads of an air valve setscrew, if no lock nuts are provided for this purpose?
6. In general, what is the procedure used to remove the pistons from compressors fitted with crossheads and piston rods?
7. If the piston rings of a compressor are worn or broken and it becomes necessary to replace them, what should be done before replacing the rings?
8. When should wrist pins be replaced?
9. Why are some compressor control valves fitted with filters filled with sponge or woolen yarn?
10. In addition to oil vapor accumulations, what other factors may cause an explosion in an air compressor?
11. If there is an abnormal rise in the temperature of air discharged from any stage of a compressor, what should be done immediately?
12. What two types of remote control are utilized for the control of steering gears on most modern naval vessels?
13. In filling a hydraulic telemotor system, what must be done before the replenishing oil is allowed to spill into the replenishing tank?
14. When a hydraulic telemotor system is exposed to low ambient temperatures, what should be the approximate cold pour range of the mineral oil used?
15. When the charging tank of a telemotor hydraulic system is being filled, why is the fluid strained through cheesecloth?
16. How is the direction and rate of fluid delivery regulated in the electrohydraulic steering gear?
17. What measures can be taken to protect the exposed parts of hydraulic rams of a steering gear?
18. How often should the oil in the high-pressure hydraulic system be filtered?

19. What condition, other than wear, generally makes frequent adjustment of windlass brakes necessary?
20. What is the primary difference between a winch and a capstan?
21. What are four principal requirements for keeping a hydraulic transmission in satisfactory operating condition?
22. If the lubricating oil pressure does not build up immediately after a Diesel engine starts, what action must be taken?
23. If there is danger of freezing during a shutdown period, what precaution must be taken?
24. How often should Diesel emergency generators be tested at full rated load and voltage for at least 12 hours?
25. If the thermostatic element of the water temperature regulator fails to operate, what should be done?
26. If the fuel service tank has been installed and an initial start is to be made, what should be done?
27. How is the overspeed trip, located in the high-pressure fuel system, generally tested?

CHAPTER 12

DISTILLING PLANTS

This chapter deals primarily with the maintenance of the two types of distilling units generally used aboard naval vessels: (1) the low-pressure steam-heated unit, and (2) the vapor compression electrically heated unit. You should be familiar with the purposes and principles of operation of these distilling plants. Detailed information concerning the construction and function of units, as well as the operating procedures for distilling plants, can be obtained from the manufacturer's instruction book for the particular type of plant on board your ship.

LOW-PRESSURE DISTILLING PLANT TROUBLES AND MAINTENANCE

Careful operation and proper preventive maintenance will, to a great extent, ensure trouble-free operation of a distilling plant. If each component part of a distilling plant is kept in proper operating condition, the full output of the plant can be maintained for relatively long periods. This can be ensured by periodic tests, inspections, and cleaning or replacing parts as necessary.

Failure to obtain full rated capacity of the plant, however, is one of the most common troubles encountered during the operation of a distilling plant. This trouble is most difficult to remedy since it may result from a combination of any number of factors. The various factors which promote full output of the distilling plant are as follows:

1. Proper steam pressure above the orifice:
   a. Ample steam supply.
   b. Proper operation of the reducing valves.
2. Highest possible vacuum in the first effect tube nest:
   a. No air leaks.
   b. Proper water levels in the evaporator shells.
   c. Evaporator tube nests continuously vented.
   d. Evaporator tube nests reasonably clean:
      (1) Continuous feed treatment and periodic chill-shocking.
      (2) Tubes mechanically or chemically cleaned when necessary
      (3) Density of brine overboard not over 1.5/32.
         (a) Overboard piping reasonably clean.
         (b) Proper valve settings.
         (c) Proper operation of the brine pump (clean suction piping and strainers; proper speed and direction of rotation; pump properly vented; gland properly packed and sealed; no air leaks in the pump piping).
   e. Evaporator tube nests properly drained:
      (1) Proper operation of all drains, and the drain regulator.
      (2) Proper operation of the tube nest drain pump.
      (3) No air leaks in drain lines.
3. Highest possible vacuum in the last-effect shell:
   a. No air leaks.
   b. Proper air ejector operation.
      (1) Clean nozzle and strainer.
      (2) Sufficient pressure and dry steam at nozzle.
   c. Ample flow of circulating water:
      (1) Clean strainer, pipe line, and tubes.
      (2) Proper valve settings.
      (3) Proper operation of the circulating pump.
   d. Effective surface in the distilling condenser:
      (1) No undue deposit inside the tubes.
      (2) Proper venting in the condenser tubes.
      (3) Proper operation of the distillate pump.

The preceding outline indicates the manner in which the listed factors affect not only one another, but also the over-all performance and output of the plant. The location of factors in the above outline does not necessarily indicate their relative importance. For example, improper operation of the condensate pump may affect the output directly, in addition to affecting the condenser vacuum. The undrained distillate will decrease the condensing surface in the distiller condenser, thus affecting the vacuum; or in some plants it may spill back into the last effect and be reevaporated.

Low Evaporator Steam Supply

The output of the plant is largely controlled by the steam pressure in the first effect-tube nest. If the required amount of steam is not supplied to the plant, full output cannot be maintained. The orifices in the steam supply line are designed to pass the proper amount of steam to permit rated capacity with a pressure of approximately 5 psi gage above the orifice. It is recommended that the orifice be inspected annually. A measurement of the orifice should be taken and compared with the figure stamped on the orifice plate. If necessary, the orifice plate should be renewed.

Any variation of steam pressure above the orifice requires an investigation, first of the regulating valve, and then of the pressure-reducing valve (if installed), to determine whether or not the valves are operating properly. If these valves are functioning properly and the pressure cannot be maintained above the orifice, an insufficient amount of steam is being supplied to the plant.

A small amount of superheat in the exhaust steam supply has little or no effect on the evaporator or scale formation but, regardless of the first-effect tube pressure used, temperatures in excess of those prescribed should be avoided to prevent formation of hard scale. The desuperheater water spray should be checked, when necessary, to see if it is operating properly.

Low Vacuum in First-Effect Tube Test

Current operating practice for low-pressure submerged-tube type units establishes that the pressure maintained in the first-effect tube nest must range from 16 inches Hg vacuum, with clean tube bundles, to about atmospheric pressure, with scaled tube surfaces. If the plant is in satisfactory operating condition, the heating surfaces will be adequate to ensure 100 percent of rated capacity within the above pressure range. With the vacuum in the first-effect tubes maintained as high as possible scale formation will be kept to a minimum and the plant will be able to operate at full capacity. Reference to the outline given earlier in the chapter shows that the primary factors affecting the first-effect tube nest vacuum are: air leakage, low water levels in the evaporator shells, improper venting of the evaporator tube nests, scale or other deposits on the evaporator tubes, and poor drainage of the evaporator tube nests.

A vacuum reduction resulting from any factor other than deposits on tube surfaces should be eliminated. This, in turn, will retard scale formation and prolong the time intervals between cleanings.

Loss of vacuum resulting from deposits on evaporator tubes should be gradual. Under normal conditions, there will be no perceptible change in vacuum for any one day's operation. A sudden drop in vacuum should be traced to causes (listed above), other than scale deposits.

AIR LEAKS.—Since the generating steam circuit operates under a vacuum ranging from 16 inches Hg to approximately 1 inch Hg (depending upon scale deposits), it may be subject to air leaks. Leaks from the steam side of the first-effect tube nest to the first-effect shell space will cause losses of capacity and economy. Air leaks from the atmosphere into the generating steam line (downstream from the orifice plate), the first-effect tube nest front header, and the first-effect tube nest drain piping (up to the drain pump discharge side) will cause a loss of vacuum and capacity. Air leaks in this part of

the distilling plant may be less noticeable than air or water leaks elsewhere because the effect on the plant is similar to the scaling of the tube surfaces. Whenever it is suspected that a low vacuum in the first-effect tube nest is being caused by air leaks, a hydrostatic test of the first-effect steam circuit should be made.

WATER LEVELS IN EVAPORATOR SHELLS TOO LOW.—A reduced first-effect tube nest vacuum and capacity can result from too low a water level in any evaporator shell. On most units, the water levels are controlled by hand regulation of the feed valves. Inability to feed the first-effect shell is usually due to scale deposits in the sea-water sides of the air ejector condenser and the vapor feed heater, or to obstructions in the feed line. Inability to feed subsequent effects is due to air leakage, or heavy scale deposits, in the feed lines between effects. It is important that the upper and lower gage glass fittings be free of scale, as plugging of these lines will result in false water level indications. Air leaks around the gage glass will also result in false levels in the gage glass.

Routine inspections and cleaning, as established by service needs, should be made for scale formation in the various component parts of the distilling plant. A check-off list, noting the last time each component part was cleaned or inspected for scale deposits, should be maintained. In this manner, preventive maintenance can be carried out with assurance that normal operation will not be affected by excessive formation of scale deposits in heat exchangers, piping, and fittings.

The pressure differential between the first- and the second-effect shells permits the second-effect feed to be discharged into the second-effect shell. Vapor leaks have occurred between the first- and second-effect shells in the two-effect single-cylinder distilling units. Large vapor leaks of this nature can be readily detected when the vacuum gage for the first-effect shell reads approximately the same as the vacuum gage for the second effect. In other words, both gages will indicate approximately 26

inches of vacuum. Such large vapor leaks, which disrupt the operation of the unit, must be located and repairs made. Large leaks can easily be found by pulling either of the tube bundles and inspecting the separator.

IMPROPER VENTING OF EVAPORATOR TUBE NESTS.—Proper venting of evaporator tube nests is very important. Upon starting a low-pressure unit, all vents leading from the steam heads to the evaporator shell should be wide open. When all systems of the distilling unit are operating at approximately normal temperatures and pressures, the vent valves should be adjusted so that they are open about 3/4 of a turn. The amount of valve opening may vary from unit to unit; therefore the actual setting must be determined by operating experience with a particular unit.

The result of improper venting of the evaporator tube nests may be either an accumulation of air in the tubes, with a loss of capacity, or an excessive loss of tube nest steam to the distilling condenser, with loss of economy. Troubles of this nature result mostly from poor operational procedures rather than from material failures.

POOR DRAINAGE OF EVAPORATOR TUBE NESTS.—Flooding of the gage glass on any tube nest drainer is a positive indication of poor drainage of that tube nest. The fact that a level is indicated in the gage glass is not necessarily an assurance of proper drainage, because air leaks at the gage glass fittings can result in false liquid level indication. When a tube nest is properly drained, the temperature of the drains is within 10° to 15° F of the saturated steam temperature in the tube nest. It is particularly important to guard against poor drainage of the evaporator tube nests. Poor drainage may result not only in a reduction in the first-effect tube nest vacuum (and consequent greater scale formation and need for more frequent cleaning), but also in a loss of condensate through the tube nest vent lines.

Adequate inspections should be made to ensure that the drain regulators are in a good material condition and

that the units perform their functions properly. Since the drain lines, up to the discharge side of the pump, are under a vacuum, precautionary measures should be taken to prevent any possible air leaks.

To ensure proper operation of the tube nest drain pump, the correct preventive maintenance procedures should be followed. The tube nest drain pump and the brine pump are subject to similar troubles.

SCALE FORMATION ON EVAPORATOR TUBES.—During normal operating conditions, scale deposits will form on the evaporator tubes of the distilling plant at a certain rate. The rate of scaling depends upon the concentration of suspended matter and carbonate salts present in the sea or fresh water used to feed the distilling plant. However, the important point to remember is that excessive scaling of the evaporator tubes can be caused by improper operation of the distilling unit.

Oil, mud, and vegetable matter leave an organic deposit, which is difficult to remove, and interferes with the proper operation of the distilling plant. When the ship is passing through water where large amounts of oil or mud are present, the distilling plant should be secured temporarily until water conditions have cleared up. Precautionary measures should always be taken to ensure that the water is suitable for uses as feed water in the distilling plant. Operation of the plant with shore-water feed should be kept to an absolute minimum because the use of some shore waters causes a tough adherent scale to form on the evaporator tubes.

Feed water treatment and chill-shocking should be considered when checking on the procedures used in operating a distilling plant. The use of proper methods will keep scale formation to a minimum, ensuring a maximum output of the distilling plant for a longer period of time. Detailed information concerning feed water treatment and chill-shocking will be given later in the chapter.

The scale deposits on evaporator tubes, in feed and brine lines, and in the brine pump, increase as the density

of the brine in the last-effect shell increases. (The density of the brine discharged overboard should never exceed 1.5 thirty-seconds.) The brine concentration is dependent mainly upon the quantity of brine pumped overboard and upon the amount of fresh water produced. If the brine concentration is too high, there will be an increase in the rate of scaling of the evaporator tubes, and the quality of the distillate may be impaired. If the brine concentration is less than 1.5 thirty-seconds there will be a loss in capacity and economy, and it will be difficult to obtain proper feeding.

The brine density must be maintained at the proper value to ensure trouble-free operation and maximum output of the distilling plant. If it is difficult to maintain the proper brine density, the brine pump and piping system should be inspected to determine the cause of the trouble.

The brine piping should be kept clean and frequent checks should be made so that scale formation is minimized. Scale inside the piping is difficult to remove. Advantage should be taken of a naval shipyard repair period to have the brine lines cleaned out by chemical methods. The valves in the brine piping systems should be maintained in a satisfactory operating condition to prevent any interference with the operation of the plant. The Macomb strainer, on the suction side of the brine pump, should be inspected and cleaned at routine intervals to prevent any excessive accumulation of scale that may result during abnormal operating conditions of the plant.

In accordance with service needs, routine inspections should be made of the brine pump to ensure that the pump is in a good material condition at all times. Wearing ring clearances should be measured and recorded. The pump impeller, housing, and associated piping should be inspected for scaling and cleaned as necessary. Pump repairs should be made before any defective conditions become serious enough to cause unsatisfactory operation of the pump.

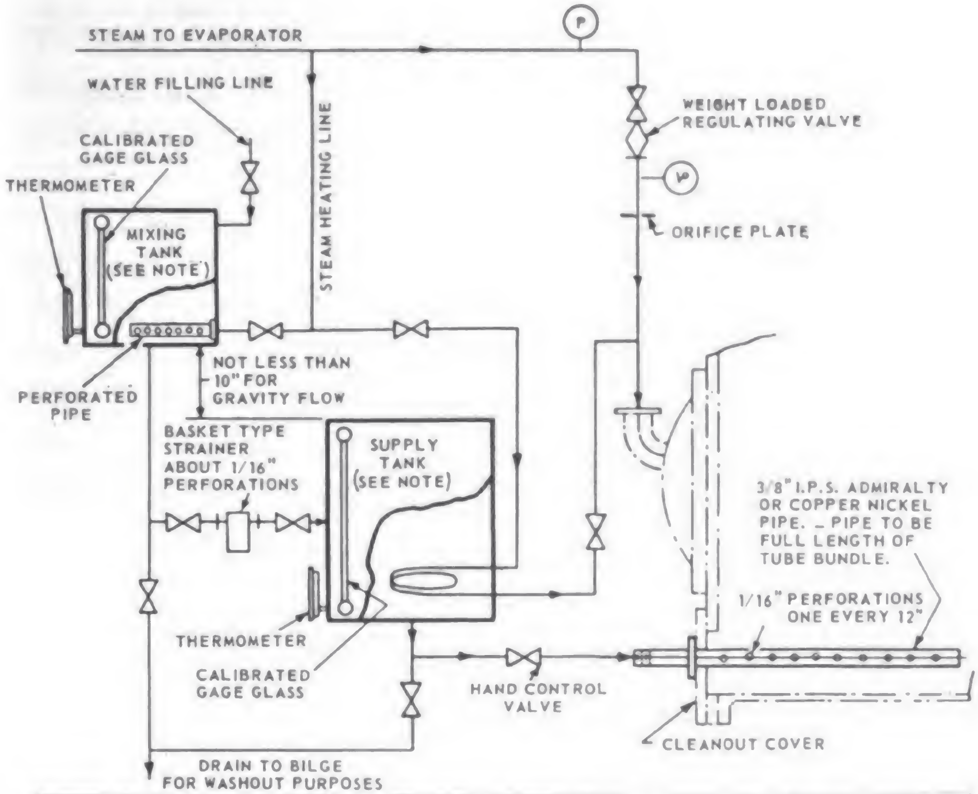
The brine pump suction is under vacuum; therefore care should be taken to maintain the vacuum side air tight. One of the major sources of air leaks is the packing glands. The brine pump gland packing should be inspected and renewed when it appears to be badly worn or too hard. The packing gland should receive sufficient scaling water, and the lantern ring should be in its proper position. Operating personnel should be cautioned not to insert any additional packing into the pump gland, from time to time, but to completely renew the packing each time it becomes necessary to make corrections. To ensure that the brine pump is properly vented at all times, care should be taken to see that the vent line is free from scale deposits which might clog the line. If the pump motor has been overhauled, precautions must be taken to see that the direction of rotation is correct.

Prevention and Removal of Scale from Evaporator

As an EN2, you must know the authorized procedures to be followed when removing scale from the evaporator tubes. When proper methods are used, scale formation can be minimized, ensuring a maximum output of the plant for a longer period of time. The authorized methods used to prevent and remove scale from evaporators are the cornstarch and boiler compound feed treatment, chill-shocking, mechanical cleaning, and acid cleaning (by naval shipyards).

CORNSTARCH AND BOILER COMPOUND FEED TREATMENT. —The evaporator feed water is generally treated with a solution of cornstarch and boiler compound. The purpose of cornstarch is to minimize priming, and the purpose of the boiler compound is to combat tube scaling. (A mixture of boiler compound and cornstarch into the first-effect shell reduces the deposit on evaporator tubes and in the brine lines.)

A diagrammatic arrangement of the feed treatment system is illustrated in figure 12–1. A mixing tank, provided with steam and filling water connections, is used



1	2		3		4	5		6	7	
Nominal capacity of distilling plant gal./day	Quantities of treatment solutions (gallons)		Recommended tank capacity as calibrated on gauge glasses (gallons)		Rate of feed for solution gal./hr.	Suggested treatment in each batch mixed*		Heat surface in supply tank coil (sq. ft.)	Size of steam lines nom. i.p.s.	
	Each batch mixed*	12 hour supply	Mixing tank	Supply tank		Corn starch	Boiler comp.		To mixing tank	To supply tank
4,000	4	8	5	10	2/3	2 oz	4 oz.	0.6	3/8"	1/4"
8,000	8	16	10	20	1 1/3	4 oz.	8 oz.	1.0	1/2"	1/4"
10,000	10	20	10	30	1 2/3	5 oz.	10 oz.	1.3	1/2"	1/4"
12,000	12	24	10	30	2	6 oz.	12 oz.	1.3	1/2"	1/4"
20,000	20	40	20	50	3 1/3	10 oz.	20 oz.	1.7	3/4"	3/8"
30,000	30	60	30	75	5	15 oz.	30 oz.	2.2	3/4"	3/8"
40,000	40	80	40	100	6 2/3	20 oz.	40 oz.	2.7	1"	3/8"

*Note that each batch is good for 6 hour supply.

Figure 12–1.—Diagrammatic arrangement of feed treatment system.

to mix and boil the cornstarch, boiler compound, and water. (The size of this tank will depend on the size of the distilling plant.) The mixture is drained from the mixing tank into the supply tank, which is equipped with a steam heating coil for the purpose of keeping the mixture warm. The supply tank has a calibrated gage glass which is used to determine the rate at which the solution is fed to the evaporator. The solution is drawn into the

first-effect shell by the shell vacuum, through a hand-controlled valve in the line from the supply tank. The table and notes (fig. 12–1), applicable to the diagram, may serve as a guide in mixing and using the cornstarch boiler compound solution for feed treatment.

The amount of boiler compound and cornstarch required varies with the character of sea water. However, it is doubtful that any increase in the quantities given on the table will ever be required since the treatment recommended was found to be effective in waters where maximum (or near-maximum) treatment is required. OVER TREATMENT MAY LEAD TO AN INCREASE IN DEPOSITS ON THE TUBES.

The cornstarch and boiler compound solution should be mixed as follows:

1. Admit to the mixing tank one-half of the water required for a batch. Fresh water at a temperature not warmer than 100° F should be used.

2. Slowly sift the dry starch into the water, stirring continuously in order to avoid lumps. (See the table for the proper amount of starch to be used for each type of plant.)

3. See that the starch is completely dissolved, and add the prescribed amount of boiler compound (see table). Mix thoroughly and bring to a boil by admitting steam, and continue boiling and stirring for approximately 10 or 15 minutes. Secure steam.

4. Discharge the mixture through a strainer into the supply tank, then add the other half of the water required to make the batch.

The solution is now ready to be discharged into the evaporator. The table gives the rate of feed for the different sizes of distilling plants. The following instructions for injecting the solution into the evaporator should be observed:

1. The solution must be stirred frequently; otherwise, the starch and boiler compound will settle on the bottom of the supply tank. If the starch and boiler compound

were properly dissolved in the mixing tank and if the solution is continuously stirred in the supply tank, as with a small motor-driven propeller, the solution may be allowed to cool gradually between batches. Otherwise, occasional heating by means of a steam coil may be required. (An open steam line is not satisfactory for heating, and an open air line is not satisfactory for agitation.)

2. The solution should be injected continuously, and at a constant rate, through a perforated pipe (fig. 12–1), into the first-effect evaporator. (Continuous injection of a mixture of boiler compound and cornstarch into the first-effect shell reduces the deposit on the evaporator tubes and in the brine lines.)

3. Once each week, the supply tank should be emptied, scrubbed, and cleaned thoroughly. The supply tank must then be filled with water and preheated to boiling in the mixing tank. Boiling must be continued for 20 minutes in order to sterilize the tank. The tank should then be drained and restored to service.

CHILL-SHOCKING.—The first-effect tube nest, in which the temperature of the tube bundle is almost equal to that of the steam supply, tends to scale up more quickly than other parts of the plant. To combat this scale, some method of chill-shocking the tubes is generally provided. This is accomplished by draining the brine from all shells, then reflooding them by means of a hose line connected to a flushing pipe or flooding connection on the shell. This chills the tube bundles, and then steam is quickly admitted into the tubes, causing differential expansion and contraction to take place, which breaks the scale loose from the tubes.

If the cornstarch and boiler compound feed treatment is not used, the distilling plant should be chill-shocked daily. If the feed treatment is used, daily chill-shocking may be desirable; however, longer intervals are satisfactory.

Although, as an EN3, you are familiar with the pro-

cedure for chill-shocking evaporator tubes, it may be helpful for you to review the Navy training course for *Engineman 3,* NavPers 10539. Additional information concerning the chill-shocking system may be obtained from chapter 58 of BuShips *Manual.*

Low Vacuum in Last-Effect Shell

Schematic diagrams in most manufacturers' instruction books indicate that a vacuum of approximately 26 inches Hg should be obtained in the last-effect shell when the initial temperature of the circulating water is 85° F, and that the vacuum should be higher when the circulating water is colder.

Failure to obtain a vacuum of 26 inches Hg, or more, should first be traced to one of the following factors: air leaks, improper operation of air ejectors, insufficient flow of circulating water, and ineffective use of heat transfer surface in the distilling condenser.

AIR LEAKS.—The importance of the elimination of all air leaks cannot be overestimated. Most distilling plant troubles result directly from air leaks. Air leaks in the shells of a distilling plant cause a loss of vacuum and capacity. Extreme care should be taken in making up all joints and keeping them tight. All joints should be tested under pressure and shellacked frequently.

There are several methods by which tests can be made for air leakage of the tube nests, heat exchangers, shell, and associated piping systems of the distilling plant. When the plant is in operation, a candle flame can be used to test all joints and similar parts that are under vacuum. In addition, soapsuds can be used to test the equipment when under air pressure. With the plant secured, air pressure tests can be used on the various component parts of the distilling plant. With the use of the manufacturer's instruction book, or blueprints, the different parts of the plant can be isolated and placed under an air test. In the same manner, air leakage may be detected by hydrostatically testing the various component parts of the

plant. When performing air pressure or hydrostatic tests, precautions should be taken not to exceed the maximum limit of the test pressures specified by the manufacturer's instruction book, or blueprints.

FAULTY AIR EJECTOR OPERATION.—Improper operation of the air ejector is most frequently caused by insufficient steam pressure or wet steam at the air ejector nozzle. During the first few months of operation of a new plant, a clogged strainer or nozzle may also be responsible for faulty operation of the air ejectors.

If necessary, the air ejector nozzle throats can be cleaned by means of the special nozzle reamers furnished each ship for this purpose, or with a wooden stick, or a piece of soft wire. Ordinary sharp-edge tools should not be used for cleaning nozzles (damage will be caused to the surface and the efficiency of the air ejectors will be impaired).

A procedure for testing air ejectors will usually be found in the manufacturer's instruction book. In general, the same maintenance procedures should be followed for air ejectors in distilling plants as for air ejectors in condensers.

The steam pressure at the nozzle inlet must not be less than that for which the air ejector is designed. There may be a substantial pressure drop in the steam line and it may become necessary to carry a higher pressure. If necessary, the air ejector steam pressure may be increased as much as 10 to 15 psi.

INSUFFICIENT FLOW OF CIRCULATING WATER.—An insufficient flow of circulating water is indicated if the temperature rises more than 20° F in passing through the condensing section of the distilling condenser. The last-effect shell pressure is directly dependent upon the distilling condenser vacuum. This vacuum is dependent upon the temperature and quantity of the circulating water, and the proper operation of the air ejectors. Too low an overboard discharge temperature of the distiller condenser circulating water causes losses in plant capacity

and efficiency. The overboard discharge temperature should be kept as high as possible, without exceeding the desired 20° F temperature rise through the distiller condenser. In addition, maintaining the correct quantity of circulating water prolongs the service life of the condenser tubes and tube sheets. When troubles occur, an inspection should be made of the condenser circulating system to determine the cause of faulty operation.

Adequate preventive maintenance procedures should be carried out to ensure that the circulating water pump, as well as other distilling plant pumps, is maintained in good material condition. Although the circulating pump does not operate under a vacuum, the maintenance and repair procedures for this pump are similar to those of the other pumps of the plant.

Routine procedures should be carried out for the inspection of the proper setting and maintenance of the back-pressure regulating valve in the condenser overboard discharge line. If this valve is not functioning properly, the valve parts should be replaced, and repairs to the valve made before its faulty operation interferes with the operation of the distilling plant.

To ensure that the condenser circulating water system is clean and free from scale and foreign matter, the piping should be inspected and cleaned in accordance with service conditions.

INEFFECTIVE USE OF HEAT TRANSFER SURFACE.—When the pressure above the orifice is 5 psi and the first-effect tube nest vacuum is several inches or more of mercury, failure of the distilling unit to produce normal full-load output always indicates improper drainage of the condenser or of one of the evaporator tube nests subsequent to the first effect. Complete flooding of the flash chamber gage glass is also a positive indication of improper drainage of the condenser. Remember that air leaks at the gage glass fittings may result in a false water level.

A temperature difference of more than 5 to 10° F between the temperature of the last-effect shell and the

temperature of the distillate at the condensate cooler inlet is another indication of improper drainage. However, the fact that this temperature difference is in the proper range does not necessarily indicate proper drainage.

Scale deposits are unlikely to form inside distilling condenser tubes if the plant is properly operated and a full flow of circulating water is maintained. However, if scale deposits occur, the tubes should be cleaned.

Venting of the vapor side of the distilling condenser is continuously accomplished by air ejectors. Venting of the salt-water side of the distilling condenser need not be continuous. Upon starting the plant, and once after each watch, the petcock vents on all salt-water heads should be opened until all air is expelled and a solid stream of water appears. Then the vents may be closed.

Another cause for low vacuum in the third effect is a failure of the distillate pump to remove distillate from the distilling condenser. Flooding of the vapor side of the condenser will result in a loss of heat transfer surface. This will cause an increase in temperature in the distilling condenser with a correspondingly lower vacuum.

The parts of a distillate pump, such as the impeller, wearing rings, and packing gland, are subject to wear and must be examined regularly and repairs made when required.

High Salinity

Excessive salinity of distillate is caused either by leakage of salt water into the vapor or the fresh water spaces, or by priming.

LEAKAGE OF SALT WATER may occur in the tubes or tube joints of the distiller condenser, in the vapor feedwater heaters, and in the distillate cooler. Individual units may be tested for leakage by proper manipulation of bypass valves around the units, if provided, and readings of appropriate salinity cells.

PRIMING is the carrying over of small quantities of brine with the vapor. It is caused by agitation of the

surface of the brine and can usually be detected by high salinity of the distillate, and, when excessive, by fluctuation of the water in the gage glasses.

The most common causes of priming are as follows:

1. Vacuum in the distilling condenser is too high.
2. Generating steam pressure is too high, particularly when the heating tubes are clean.
3. Fluctuating generating steam pressure or temperature.
4. Feed-water level in the shells is not carried at the proper points.
5. Unsteady feed.
6. Unsteady brine discharge.
7. Salinity of the brine in the last effect is too high.
8. Improper venting or draining of tube nests.
9. Improper functioning of the vapor separators, due to clogging.
10. Leaky tube in the evaporator tube nest.

In order to determine the cause for excessive salinity of the distillate, first make certain that priming does not exist. During the normal operation of the distilling plant, the selector switch of the salinity-indicating system should be set to indicate the purity of the distillate pump discharge, which is the combined output of all the evaporator effects of the unit. If high salinity is indicated, the selector switch for the cells should be turned successively to indicate the salinity at the various points in the system where cells are located. In all cases, extreme care should be taken to make proper adjustments for temperatures.

If the salinity cell in the distilling condenser drain line (ahead of the flash chamber) indicates high salinity, the trouble is probably due to excessive vacuum, excessive capacity, high feed-water level in the last-effect evaporator shell, high brine density in the shell or a leaky tube in the distilling condenser or third-effect tube nest.

If the cell in the third-effect tube nest drain line (or second effect in double-effect plants) indicates high salin-

ity, the trouble is probably due to high feed-water level in the second-effect shell, a leaky tube in the second-effect vapor feed heater or third-effect drain feed heater or second-effect tube nest, or contaminated drains from the second-effect evaporator tube nest.

If the salinity cell in the tube nest drain line from the second-effect evaporator of a triple-effect plant indicates high salinity, the trouble is probably due to a leaky tube in the first-effect evaporator tube nest or first-effect vapor feed heater, or high feed level in the first-effect evaporator shell.

Unsteady operating conditions such as variations in generating steam pressure or temperature, variations in last-effect vacuum, and variations in the rate of feeding also have marked effects on the purity of the fresh water produced by the plant. In addition, any or all of the above cells may indicate high salinity under such operating conditions. Leaky tubes in various heaters and coolers may be detected by bypassing the units. If contamination disappears when a unit is bypassed, a leaky tube is indicated. Leaking external feed water heaters may be bypassed without permanent injury until it is convenient to repair them, but since the economy of the plant is adversely affected, leaky heaters should be repaired as soon as possible.

If high salinity is indicated by the cell located in the first-effect tube nest drain when the plant is shut down, a tube leak in the first-effect evaporator tube nest is indicated. During operation, such a leak would not be detected because the pressure is less in the shell than in the bundle.

On plants equipped with tube nest drain feed heaters, a high salinity reading from this cell (during operation) indicates a leak in the heater.

A high salinity reading in the cell located in the drain line of the air ejector condenser indicates a leaky tube in that unit.

After a leaky unit has been found, place the unit under a hydrostatic test and locate the leaking tube or joint.

Testing for Salt-Water Leaks

If a leak is detected in a heat exchanger, the defective tube(s) should be located by means of an air pressure or a hydrostatic test, in accordance with the recommended procedure in the manufacturer's instruction book. Blueprints should also be used to study the construction details of the individual heat exchanger.

As soon as a leaky tube has been located, it should be plugged at both ends. Special composition plugs, which are provided in the allowance of repair parts, should be used. (The data regarding the number and location of plugged tubes should be entered on the Machinery History Card for the unit of the distilling plant.)

Since plugging the tubes reduces the amount of heating surface, the heat exchanger will fail to give satisfactory performance after a number of tubes have been plugged. It will then become necessary to retube the heat exchanger. Under normal conditions, this work should be accomplished by a naval shipyard or tender. However, repair parts and a number of special tools are included in the ship's allowance list, so that emergency repairs can be made to the heat exchangers and to other parts of the distilling plant.

REMOVABLE TUBE BUNDLE. To find which of the tubes within a bundle is leaking, it is necessary to test the individual bundles hydrostatically. If the leak is in a removable bundle (vapor feed heaters when within an evaporator shell, evaporator tube nests, distilling condensers on Soloshell end-pull plants), the bundle must be withdrawn and a hydrostatic test at full pressure (50 psi) must be applied on the tube side.

NONREMOVABLE TUBE BUNDLE. If a leak occurs in a nonremovable bundle (distillate coolers, air ejector condenser, external vapor feed heaters), the tube nest covers

must be removed, and the full test pressure (50 psi) applied on the shell side of the unit.

If a nonremovable distilling condenser bundle is within an evaporator shell, the tube nest covers must be removed and a full test pressure of 30 psi should be applied to the evaporator shell.

If the distilling condenser is fitted with a diaphragm-tube (Goubert) expansion joint, a test ring will be required to replace the tube nest cover for testing. (This ring is provided in the spare parts box.)

Cleaning Operations

The capacity and economy of the distilling plant are affected by the cleanliness of the various heat exchanger surfaces. Except for the evaporator tube nests, the heat exchanger surfaces require cleaning only at infrequent intervals. The evaporator tubes may require more frequent cleaning, depending upon the operating conditions. Periodic checking of the feed and the drain temperatures, under similar operating conditions, will indicate the efficiency of the various heat exchangers and the cleaning requirements.

The method used to clean the inside surface of the heater and the condenser units depends upon the nature of the deposit. In all units operating at lower temperatures, the deposit may be such that it can readily be flushed out with water at a high velocity. However, in units operating at higher temperatures (air ejector condenser, and vapor feed heaters), a harder deposit may accumulate and require the use of an air-driven revolving tool. (The latter is so constructed that the cutting edge cannot cut into the thin tube wall.)

EVAPORATOR TUBES.—Scale deposits on the evaporator tubes will not appreciably reduce plant output until the deposits have caused a reduction in the first-effect tube nest vacuum to 1 or 2 inches mercury (Hg). When scale deposits cause the vacuum to approach zero, the tubes

must be cleaned in order to keep the plant operating at its maximum efficiency. When the plant is properly operated and the feed water has been treated, the interval between cleanings should be at least 6 months.

An approved method of cleaning by circulating dilute muriatic acid through the system has been established for accomplishment by naval shipyard personnel only. In addition, the use of sulphuric acid for cleaning tubes has been authorized for tenders. When acid cleaning cannot be accomplished, the unit should be mechanically cleaned in accordance with the following instructions:

The evaporator tube bundles must be removed from the shell for cleaning. In order to provide convenient access for cleaning and repair purposes, LIFTING GEAR (suitable to the type of installation) is generally furnished for the removal of tube bundles.

Some installations are provided with an overhead trolley from which the tube bundle may be suspended for cleaning. Other installations are equipped with tracks and roller brackets, bolted to the front head of the tube bundles.

For small tube bundles, however, special external lifting gear is omitted because the bundles can be handled easily with an ordinary CHAIN FALL, or MANUALLY (by several men).

When a tube bundle is withdrawn beyond the support plate, the tube nest stop should be bolted in place to prevent accidental dropping of the rear head. The tubes are cleaned with a light scaling tool operated by a light air hammer. The tool should be held against the tube with moderate pressure, and moved over the entire length of the tube. Every tube in the bundle must be cleaned, as missing one will impair the output of the plant and also make cleaning more difficult in the future.

A torch should never be used for descaling a tube nest made up of straight tubes, as the expansion and contraction caused by the heat may cause the tubes to loosen at their joints.

After cleaning the tubes, a hydrostatic test of 50 psi should be applied to the bundle before replacing it within the shell. (This test will indicate leaks, if any, in the tubes.)

Individual leaky tubes are commonly corrected by plugging both ends of the tube with a standard fiber or metallic plug, or a tapered hardwood plug (in emergencies). Too many plugged tubes will, however, reduce the heating surface, and, in some multipass heat exchanger units, may cause excessive tube velocities. When this condition exists, THE LEAKY TUBES MUST BE REPLACED.

When it becomes necessary to renew individual tubes in the tube nest, the following steps (explained in detail in BuShips *Manual* and in manufacturers' instruction books) should be taken:

1. Loosen the tube at both ends from the tube sheets, using the equipment designed for that purpose.
2. Drive the tube from the nest.
3. Inspect the tube sheet holes carefully and remove all foreign matter using the reamer provided. If necessary, use a reamer of slightly larger diameter to refinish or to remove imperfections from the tube holes.
4. Clean the ends of the replacement tube thoroughly. Insert the tube in the tube sheet holes so that it extends about 1/16 inch from the tube sheets at both ends. (A drop or two of lubricating oil should be placed inside each tube to lubricate the expander rolls.)
5. Roll the tube to make a tight joint, using the prescribed tube rollers.
6. Bell, or flare, the tube out into the tube sheet. (Tubes may be flared at both ends, and must be flared at the inlet end. The belling tool is furnished with each plant, and is used by driving it endways into the tube until the tube is opened up at the end and fits snugly into the flare in the tube sheet.)
7. Machine or grind the expanded and belled tube down flush with the surface of the tube sheet.

8. Place the tube nest under a hydrostatic test pressure of 50 psi and clean the internal feed pipe, chill-shock or flushing pipes, etc.

9. Replace the tube nest in the evaporator shell, and seal the shell with the front head, fittings, and lines. The plant should then be tested for leaks.

INTERIOR PARTS.—When the distilling plant is dismantled for cleaning evaporator tubes, a number of other parts should be inspected, and cleaned if necessary. The feed water distributing pipes, flushing pipes, and separate drain lines should be removed, and any scale deposits cleaned out. The hooks on the lower baffles, and the troughs formed by these baffles and the shell, should be cleaned to ensure proper drainage. The upper and lower gage glass equalizer lines, the gage glass fittings, the gage and sight glasses, the feed lines between the effects, the brine lines, and the pump impeller should all be inspected and cleaned, if necessary. The scale should be removed mechanically.

If the above maintenance is performed at a naval shipyard, any parts which can be removed from the ship may be cleaned in the shop by dipping in weak acid solutions, followed by thorough flushing. Since the use of acid is extremely hazardous to both personnel and material, its use as a cleaning agent by ship's personnel is prohibited. Naval shipyards may use a weak acid solution for cleaning interior parts of a distilling plant.

HEAT EXCHANGERS.—Under certain operating conditions, scale deposits may accumulate inside heat exchanger tubes, particularly in the air-ejector condenser and in the first-effect feed heater. Every 6 months, or whenever the distilling plant is secured for descaling evaporator tubes, the inside surfaces of the heat exchanger tubes should be inspected and cleaned, if necessary. Neglect can lead to thick scale deposits which are difficult to remove.

For mechanical cleaning, the distilling condenser on

Soloshell end—pull plants must be removed to be inspected and cleaned. On other type plants, the distilling-condenser tubes can be made accessible for inspection and cleaning by removing the heads at both ends. The air-ejector condensers on all plants can be opened for cleaning by removing the heads at both ends. The vapor feed heater bundles on practically all installations must be removed before cleaning.

The cleaning of these tube bundles is accomplished by means of an extended shank drill, driven by a reversible motor at 250 to 300 rpm, or by standard tube cleaning equipment adapted for use with 5/8-inch O.D. condenser tubes.

VAPOR COMPRESSION PLANTS

At present, the Navy employs vapor compression distilling plants on submarines and on small Diesel-driven surface vessels, where the absence of any steam supply necessitates some other source of heat supply for the evaporating process.

Of the two designs used aboard naval vessels, the older design is the Model S rated at 750 gallons of distilled water per day. It is efficient and compact in design, but has the disadvantage of being difficult to keep clean and to overhaul.

The newer design is made in two models: Model X–1, with a rated capacity of 1000 gpd; and the Model X–2, which has twice the capacity. Since the maintenance problems are the same for the Model X–1 and the Model X–2 units, the section of the chapter devoted to the Badger design deals principally with the former units.

Model S Units

Since you may be assigned to a ship equipped with the Model S distilling unit, you should be familiar with the maintenance of these units. Figure 12–2 shows a schematic view of a Model S distilling unit.

PREVENTION OF SCALE FORMATION.—During the normal

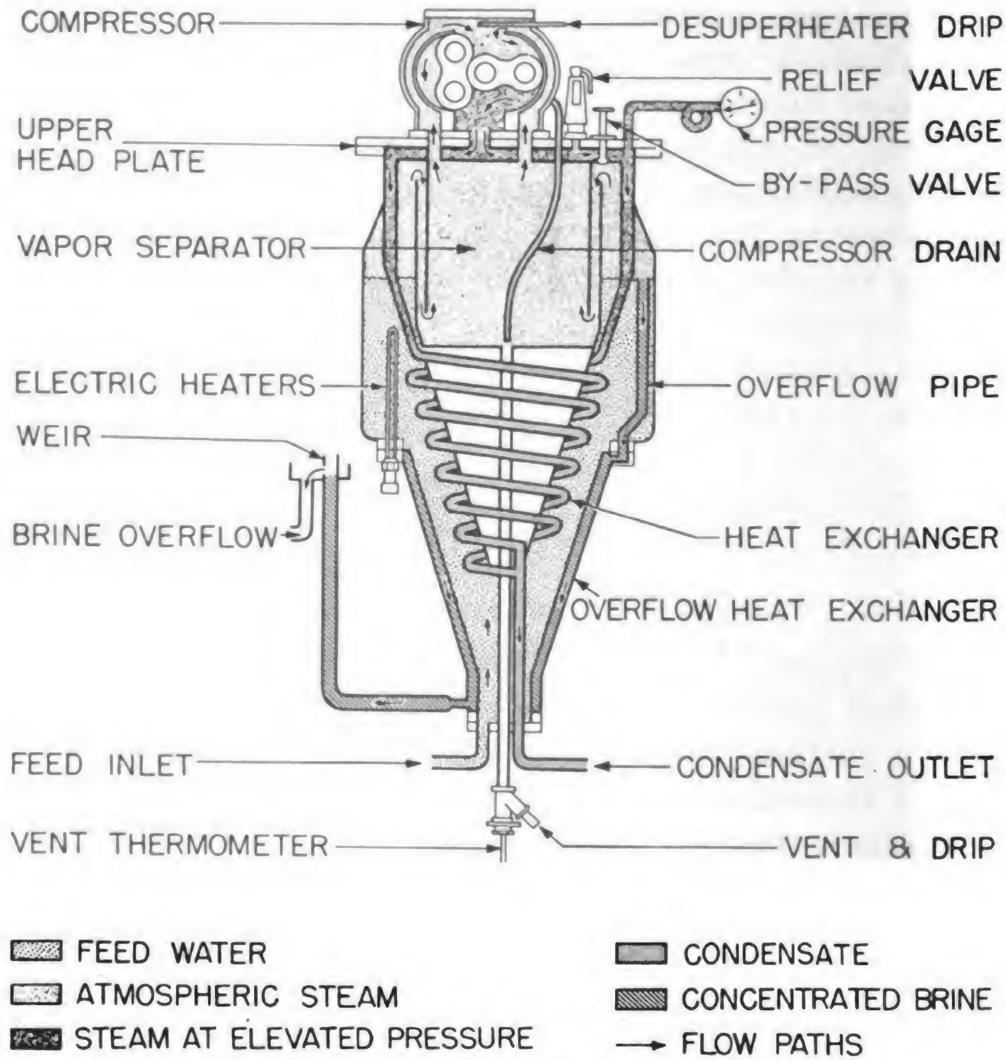


Figure 12–2.—Model S distilling unit, schematic view.

operation of the Model S unit, scale gradually accumulates on the heating surfaces and reduces the capacity until cleaning becomes necessary. In addition, if the unit is operated continuously for a long period, scale deposits on the coils tend to make the coils and the spacer cones stick together and hard to separate. Since the heat exchanger tubes are made of copper-nickel (a comparatively soft metal), an attempt to separate the coils from the spacer cones will result in damage.

Scale formation may be minimized, as well as prevented, by observing the precautions outlined in the paragraphs which follow.

The desuperheater drip should be sufficient to remove all superheat from the vapor at the compressor discharge. (The desuperheater drip must be operating at all times when the compressor is running.) The following table gives the saturated temperature of steam at the pressures encountered, and at those pressures which should be maintained, during normal operation:

Pressure, psi gage:	*Temperature, °F*
2.0	218.5
2.5	220.0
3.0	221.5
3.5	223.0
4.0	224.4
4.5	225.8
5.0	227.2
5.5	228.5
6.0	229.7
6.5	231.0
7.0	232.3

Whenever the still is secured, and not less than once each 24 hours, the still should be flushed, in accordance with manufacturer's instructions, for 1½ to 2 hours. After flushing, the still should be kept full of water until it is restarted.

Every 10 to 20 hours of continuous operation, all heaters should be turned on, and the unit operated for about 3 hours with the maximum feed and overflow obtainable with stable operation. The compressor discharge pressure should be maintained as low as possible. However, if the compressor discharge pressure continues to increase and fails to return to the initial operating pressure, after flushings, additional heaters should be used and the overflow rate increased for the remainder of the watch, or until the compressor discharge pressure is reduced by flushing.

Periodic flushings will retard the scale formation and prevent the rapid building up of operating pressure;

nevertheless a gradual increase in pressure will occur during continued operation. A safe rise in pressure from an initial operating pressure of 3.5 psi may be considered as approximately 2.25 psi (5.75 psi is the upper limit of compressor gage pressure at a compressor speed of 1100 rpm). In an emergency, 6.25 psi may be used as the upper gage pressure limit.

If the degree of scaling is such that the discharge pressure goes above permissible limits, chemical cleaning will be extremely difficult; scale removal then must be accomplished by mechanical cleaning. To simplify cleaning operations, efforts should be made by flushings and by other means in order to prevent compressor discharge pressures of 5.75 psi, or more. As a result of this practice, the stills can be easily cleaned by chemical means, and the plant will not have to be disassembled for each cleaning.

METHODS OF CLEANING THE UNIT.—The Model S distilling unit may be cleaned by completely dismantling the tube nest assembly and removing the scale with copper scrapers and wire brushes. In addition, the unit may be cleaned by circulating a cold solution of hydrochloric (muriatic) acid in water (6.8 percent by weight), through the distilling unit, at the rate of 60 gallons per hour for 2 hours. The latter method should be used only when alongside a tender or at a base where special equipment is available. When a tender or base is to disassemble a unit for checking, repairs, or for mechanical cleaning, the acid-cleaning method should first be used in order to facilitate the dismantling procedure.

Detailed instructions for disassembling a Model S distilling unit may be obtained from the manufacturer's instruction book. However, the following steps are recommended by the Bureau of Ships:

1. Turn the electric heating plugs (locking type) about 1/4 turn before withdrawing. However, the heaters should not be removed until step 4.

2. Remove the bottom cover by using jack bolts, provided to break the gasketed joint. Remove two nuts from the center flange studs, slip over the bottom cover studs, and replace two bottom cover stud nuts. Then tighten the larger nuts so that the inner and the outer cone sections can be held together.

3. Remove the lower part of the shell by removing all the nuts at the middle flange of the shell, and break the gasketed joint. Do not twist or bend the shell until it has been lowered sufficiently to clear the heaters from the vertical stem headers and the tube nest.

4. Remove the heaters, by using a special wrench from the tool kit, after the electric plugs (locking type) are turned 1/4 turn. Separate the two sections of the conical shell that form the overflow heat exchanger.

5. Clean the surfaces of both shells and of the inner cone by using copper scrapers and wire brushes. (The shells and the inner cone are constructed of copper-nickel and may be damaged by using hard metal scrapers or brushes.)

6. Insert pins (from the spare parts box) into the clips on each side of the separator baffle to support it while the coils are being removed from the inner coil cone.

7. Clean as much of the outer (lower) coil surface as possible by brushing and scraping. Note that the tubing is thin (#20B.W.G.), and care must be taken to prevent damage to the coils. Cleaning of the coils and the separator cones will be made much easier if the surfaces are kept wet.

8. Disconnect the unions which secure the outer (lower) coil to the vapor and the condensate headers. Remove the coil and the 3 spacer cones, tapping lightly with a wooden mallet, if necessary. (A special wrench for the unions and a wooden mallet will generally be found in the spare parts box.) Extreme care must be taken NOT to let coils drop, and to support the coils (dur-

ing and after cleaning) so that the ends of the coil will not become damaged or bent. A stand should be used for this purpose, but if none is available, the coils may be placed in the lower shell for protection.

9. Remove and clean the coils individually. As each coil is removed and cleaned, it should be tagged or otherwise marked, or stowed, so that it may be replaced in its original position. (Never attempt to remove more than one coil at a time from the distilling unit. If the coil sticks, light tapping around the top third of the coil with a wooden mallet will loosen it.)

10. Remove the pins from the vapor separator, lower and clean in the same manner as the shell sections. Clean the 8 downcomers (vapor headers) and the inner cylinder of the vapor separator.

Information concerning the reassembly and testing of the unit may be obtained from the manufacturer's instruction book for the specific unit. However, the following steps have been recommended by the Bureau of Ships:

1. Align a small arrow stamped on the tab of all coils with an arrow stamped on the upper head plate below the pulley.

2. After tightening the nine unions on the first coil replaced, plug up the open unions on the discharge header. Connect a rubber hose to the outlet of the discharge header and fill the tubes with fresh water until it runs out of the top unions.

3. Inspect the bottom union and small coil header for leaks. If any union leaks, it can be corrected by lapping the contacting surfaces with opposite parts of a spare union. Each union should have a thin film of white lead paint on the contact surfaces before being made up. (It is important to note that, during this operation, only the lower header connections are tested for leaks. Since a leak in any coil can only be corrected by removing the coils below it, each of the lower unions and headers must be tested and tightened before the next coil is installed.)

4. Raise each coil with the jack until the union on the small coil header lines up with the union on the discharge header. The coil must be jacked up so that the bottom union makes up exactly. The union should be started by hand and the threads MUST NOT be crossed. (If a jacking cone is not available, a block of wood may be used under the 3/8-inch diameter circular bottom header of the coil to cushion and distribute the pressure of the jack. DO NOT apply any pressure on the 1/4-inch tube that leads from the 3/8-inch header at the bottom of the coils.)

5. After the bottom union is tightened firmly, the jack should be lowered until there is no pressure on the bottom of the coil. This permits the upper unions to be rotated so that they can line up with the half unions on the vertical steam headers. The coil should then be jacked up again until the unions can be started by hand without bending the tubes.

6. Tighten the top unions and remove the jack.

7. Replace the coils and cones in the same relative position to each other as originally installed.

8. Test the coil assembly for tightness by connecting a rubber tube or hose to the outlet of the condensate discharge header and filling the entire bundle with distilled water (about 2 gallons).

9. Elevate the open end of the hose above the upper unions on the coils in order to make certain that the tube assembly is completely filled. Leaks in all upper unions will be indicated by water dripping and may be corrected without removing the coils. Leaks in the lower unions (connecting to condensate header) cannot be corrected without removing coils. Therefore, each of the lower unions and the 1/4-inch tubes to which the unions are attached, as well as the connections to the 3/8-inch bottom header rings, should be tested individually when the coil is installed as specified in step 3 above.

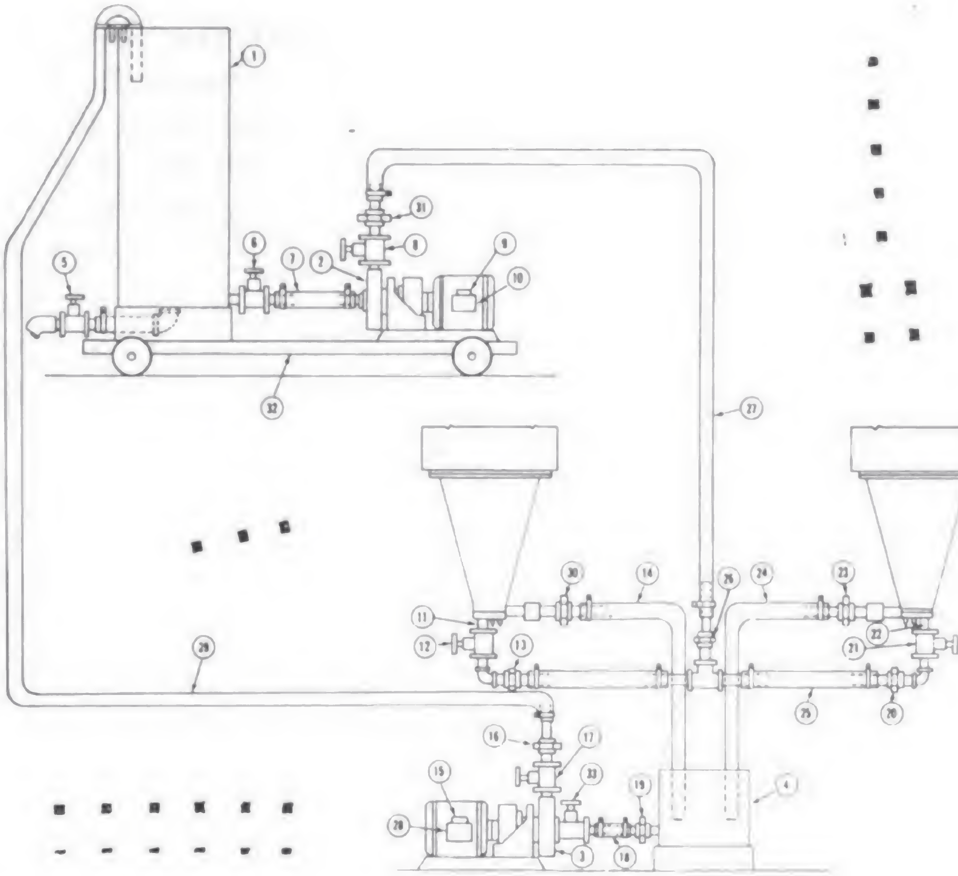
10. Place the upper section of the shell in position by matching the arrow on flange with that on the top plate. (During reassembly, care must be taken to prevent damage to heater units by fouling with the tube nest or the vapor headers.)

11. Pull up the nut on the vent pipe tightly. (This nut acts as a packing gland nut and ensures a tight nesting of the 10 coils. A loosely nesting set of coils will permit the feed to short circuit rather than travel in a spiral path parallel to the axis of the tubes, and cause too great a difference between the condensate and feed temperature, allowing excessive heat loss in the condensate. This in turn would make it impossible to operate the unit with the correct amount of overflow.)

12. After all the joints are tightened, check the heaters by cutting in heater switches individually and observing the ammeter reading for each. Two heaters are controlled by each switch, and if all heaters are in operation, the ammeter reading, for each switch, should be the same.

As mentioned earlier in the chapter, the hydrochloric (muriatic) acid method of removing scale and cleaning the Model S unit should be used only by a tender, a base, or an activity having the required special equipment. A diagrammatic arrangement of the equipment for acid cleaning two distilling units is illustrated in figure 12–3. (The acid cleaning equipment should be procured for each base and tender.)

The Model S unit may normally be cleaned by circulating, through the unit, 6.8 percent by weight of hydrochloric (muriatic) acid in water. A 6.8 percent acid solution may be made by adding 2 gallons of concentrated commercial muriatic (20 Baume) to 10 gallons of fresh water. A charge of 30 gallons of the 6.8 percent acid solution is required per still. The acid solution should be circulated at a rate of about 60 gallons per hour per still.



1. Rubber tank (battery jar).
2. Acid-proof pump and motor.
3. Acid-proof pump and motor.
4. 9-gallon rubber bucket.
5. Rubber diaphragm drain valve.
6. Rubber diaphragm valve.
7. Connecting hose.
8. Rubber diaphragm valve.
9. Switch for motor.
10. 50-foot extension cord with plug.
11. Rubber nipple with valve.
12. Rubber diaphragm valve.
13. Rubber union.
14. Extension hose.
15. Switch for motor.
16. Rubber union.
17. Rubber diaphragm valve.
18. Rubber hose connection with union.
19. Rubber union.
20. Rubber union.
21. Rubber diaphragm valve.
22. Rubber nipple with valve.
23. Rubber union with nipple and coupling.
24. Extension hose.
25. Connecting hose.
26. Rubber union.
27. Extension hose.
28. 50-foot extension cord with plug.
29. Extension hose.
30. Rubber union with nipple and coupling.
31. Rubber union.
32. Truck.
33. Rubber diaphragm valve.

Figure 12–3.—Acid cleaning Model S distilling units.

Referring to figure 12–3, the following procedure should be observed when hydrochloric acid is used to clean the Model S unit:

1. Drain the unit(s) and disconnect the feed, the condensate, the vent, and the overflow piping at the base of the unit. It is important to note that with all the piping removed there will protrude from the bottom plate a 1/2-inch vent pipe and a 3/8-inch condensate pipe, each with a packing nut to make a tight joint. The 1/2-inch tapped hole in the bottom plate is the feed connection and should be used for connecting the acid circulating pipes. (The acid circulating pipe lines MUST NOT be attached to the vent or the condensate connections.)

2. Screw the rubber nipples with valve elbow and part union connection attached (items 11, 12, 21, and 22 of figure 12–3) to the feed connection in the bottom plate of the distilling unit. Always apply the special pipe compound to the thread before screwing into the bottom plate.

3. Connect the two feed connections together with the rubber connection (item 25 of figure 12–3) consisting of hose, rubber tee, and part unions. Make up the unions (items 13 and 20).

4. Screw the couplings attached to the part unions (items 23 and 30) over the 1/2-inch overflow nipples extending from the side of the distilling unit near the bottom. Use the pipe compound on the threads.

5. Attach the rubber hose extensions (items 14 and 24) to the connections (items 23 and 30), and make up the unions.

6. Place the 9-gallon rubber bucket directly below the distilling units and put the ends of the rubber hose extensions (items 14 and 24) into the bucket.

7. Connect the bucket to the suction of the recirculation pump (item 3) using the extension hose (item 18) and make up the union (item 19).

8. Connect the rubber extension hose (item 29) to the discharge of the recirculation pump and make up the union (item 16). Place the opposite end of the hose in top of the 60-gallon battery jar.

9. Connect the extension hose (item 27) to the discharge of the feed pump (item 2) and make up the union (item 31). Extend the hose to the distilling units and connect up to the rubber feed connections making up the unions (item 26). Note that the battery jar, feed pump, and all connections between the feed pump and the battery jar, drain connection from the battery jar, etc., will be mounted on a truck and remain permanently connected.

10. Connect the extension cords to the plugs in the submarines, or to the power supply on tender or at base as available.

11. Close the rubber diaphragm drain valve, and all the rubber diaphragm valves.

12. Fill the battery jar with fresh water (using water from an available hose at the base or tender). Measure 60 gallons into the battery jar by filling to the 60 gallon mark in the jar.

13. Open the proper rubber diaphragm valves (items 6, 8, 12, and 21). Start the feed pump by turning on the switch for the motor (item 9) and fill the distilling units (with water) until the water flows from the overflow hose connections. Fill the bucket about 3/4 full. Close the proper diaphragm valves (items 12 and 21).

14. Open the proper valves (items 17 and 33), and start the pump. When the pump starts taking water from the bucket, throttle the valve (item 17).

15. Open the proper valves (items 12 and 21) until a full stream of water is running from the overflow hose connections (items 14 and 24) into the rubber bucket.

16. Adjust the valve on the recirculation pump discharge (item 17) until the level in the 9-gallon bucket remains constant.

17. Circulate the water freely through the distilling units for about 15 minutes, with the diaphragm valves (items 12, 17, and 21) properly adjusted in order to provide a balanced flow.

18. Examine all the connections to make certain that no leaks exist. (NO ACID MUST BE ALLOWED TO LEAK INTO THE VESSELS.)

19. Measure 12 gallons of 20° Baume muriatic acid, using a small rubber bucket (3-gallon) as a measure, and add slowly to the water in the battery jar. After all the acid has been added, circulate the solution through the distilling units for two hours.

20. At the end of the two hour cleaning period, remove the hose from the battery jar and discharge the acid solution overboard. When the level of the solution in the battery jar has been lowered to just above the circulating pump suction connection, fill the jar with fresh water and make up the water loss by continuous feed.

21. Continue to flush out the unit for one hour, adding fresh water continuously to the battery jar and discharging overboard through the hose.

22. Secure the pumps, disconnect the rubber piping, and drain the distilling units.

23. After every sixth acid cleaning, the shells of the units should be removed, inspected for scale, and cleaned, if necessary, as explained in the mechanical cleaning section.

When only one distilling unit is to be cleaned, the feed hose union may be attached directly to the feed valve connection (refer to items 26 and 13 of figure 12–3), and one overflow pipe can be connected. Half of the specified quantity of acid and water will be required.

VAPOR OR OIL LEAKS IN THE COMPRESSOR.—Vapor is prevented from leaking outward along the shaft by four seals. Any vapor escaping outward along the impeller collars on the shaft sleeves passes into a space inside the vapor seal, directly connected to the suction side of the compressor. Therefore, the greater part of any leakage

is returned directly to the vapor space. As the seals become worn, some vapor may also pass through the seal into the spaces between the vapor seals and the bearing carrier. (In earlier designs, these spaces were drained and vented to the atmosphere through petcocks. In later designs, the spaces were drained and vented through the top cover plate of the distilling unit and into the upper end of the vent and drain pipe from the vapor separator.)

The oil contained in the reservoir formed by the drive cover is prevented from leaking outward along the drive pulley shaft by double seals. At the gear and pulley ends, as well as on both shafts, rotary seals are provided to prevent oil flow inward from the bearings.

If oil leaks into the vapor compartment of the compressor, it will be carried down and deposited in the 1/4-inch tubes of the heat exchanger, and a thin film of oil will appear on the surface of the condensate. This oil film deposit inside the tubes will result in a decrease in heat transfer through the tubes, with a corresponding rise in compressor discharge pressure.

To remove this oil deposit, proceed as follows:

1. Shut down the distilling unit and flush with the feed pump until the overflow runs cool.
2. Shut off the feed.
3. Disconnect the condensate piping and make a hose or piping connection from the condensate header, with the open end slightly below the top cover plate.
4. Add about 2 or 3 gallons of pure oil solvent, such as naphtha, until the open end of the connection overflows; this indicates that the tube bundle is full. After a few minutes, drain and repeat with the same solvent.
5. Reconnect the condensate piping and start the distilling unit.
6. Discard condensate until all traces of the solvent have disappeared.

LUBRICATION OF THE COMPRESSOR.—The compressor is lubricated by two oil reservoirs, one at each end. The

oil level should be checked every 24 hours after the compressor has been stopped for approximately 20 minutes, and oil added as necessary to bring the level to the proper gage level.

Since all the bearings and the gears run at a high temperature, no oil lighter than Navy Symbol 1150 (SAE 70) should ever be used.

Model X–1 Units

Compared with the Model S unit, the Model X-1 unit differs primarily in the mechanical design and in the arrangement of parts. The Model X-1 unit has short, straight tubes instead of the coiled and nested tube bundle. Mechanical cleaning, which may be done by ship's forces, is simpler and less hazardous than the hydrochloric acid cleaning process, the latter method is prohibited for Model X-1 units. The preferred method of cleaning is the sodium acid-sulphate method, described later in the chapter.

The feed is inside the evaporator tubes and heat exchanger tubes, both readily accessible. In the heat exchanger, the overflow brine is also inside the inner tubes (fig. 12–4), and scale can be removed by the use of rotary tube cleaners.

CLEANING THE EVAPORATOR.—Maintenance of the evaporator consists for the most part of periodically cleaning the unit. The evaporator should be cleaned after each 400 hours of operation and MUST be cleaned after each 500 hours. When the evaporator is cleaned, the overflow pipe, the rotameter, the manometer, and the flow-control valve should also be cleaned. (It may be necessary to clean the measuring devices more frequently in order to keep the markings clear and distinct.)

The cleaning crew, for the evaporator, consists of two men, one to operate the motor, the other to handle the tube cleaner. When cleaning evaporators, an important point to note is that the driving belt must have sufficient

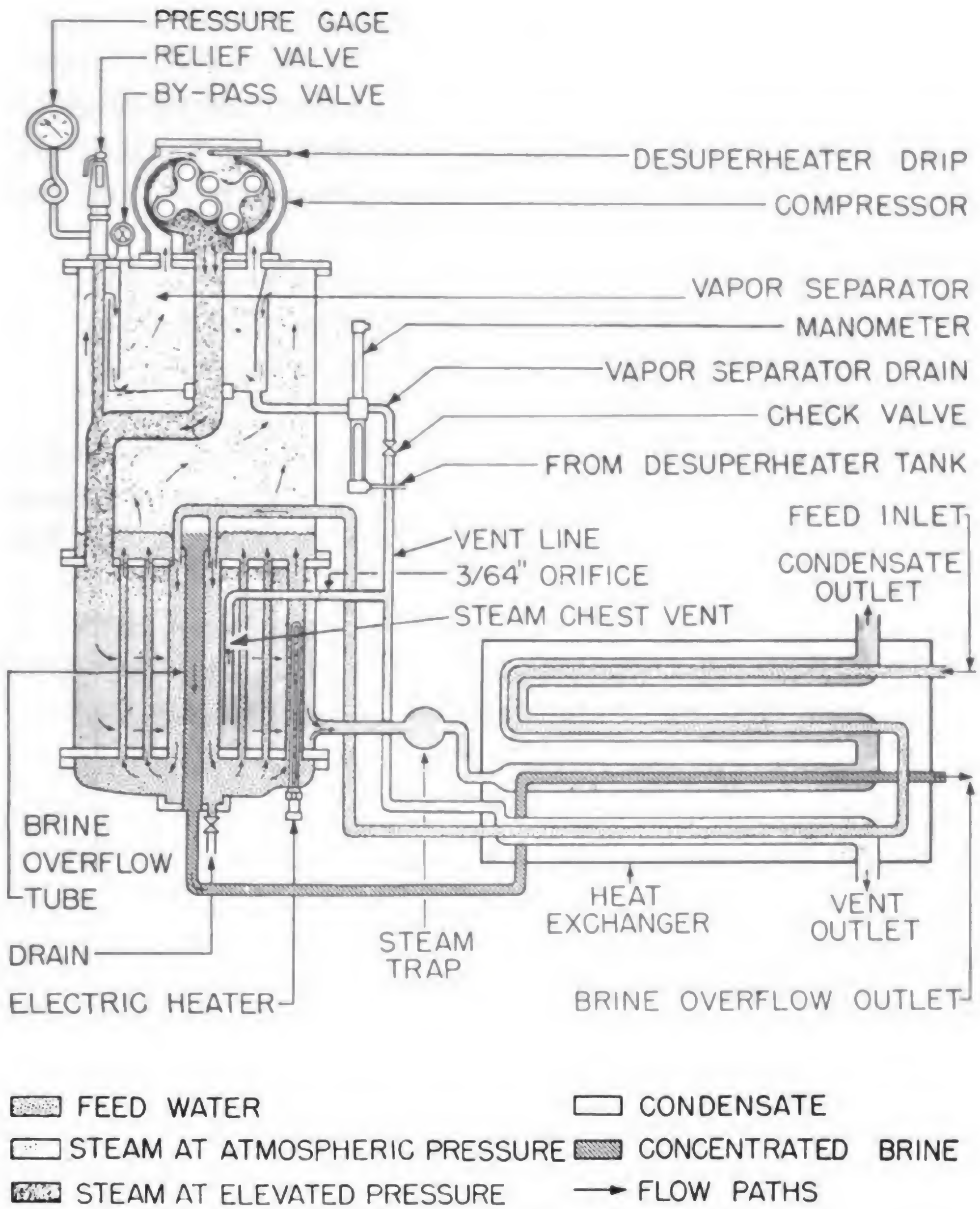


Figure 12–4.—Model X distilling plant, schematic view.

slack so that it will slip if the cutter bit becomes jammed in the tube.

The evaporator should be cleaned as follows:

1. Remove the insulation from over the cover, and take off the manhole cover. (If necessary, rig a platform for the man working in the evaporator.)

2. Open the drain valve at the bottom and drain the evaporator.

3. Remove the circular insulation from the bottom of the evaporator.

4. Disconnect and remove the heaters, using a special thin heater wrench. Plug the openings for heaters with pipe plugs which are provided for this purpose, and generally carried in the tube cleaner box.

5. Clean scale from the heaters, while wet.

6. Disconnect the overflow brine piping from the handhole at the bottom of the unit, and plug the hole with a pipe plug.

7. Start the feed pump, open the flow-control valve, and fill the unit until the water level is approximately 1/8-inch below the top of the tubes. Secure the feed valve and pump.

8. Place a light in the evaporator.

9. Disconnect the feed line by breaking the union just inside the shell, and remove the feed pipe.

10. Unscrew and remove the overflow funnel pipe.

11. Chip scale from the compressor discharge pipe, underside of the baffle, and from within the shell, to about 4 inches above the tube plate. In order to prevent large chips of scale from falling into the tubes, it is best to cover the tube plate.

12. Remove the motor and flexible shafts from the tube cleaner box and connect them, in accordance with manufacturer's instructions. In addition, detailed information may be obtained from chapter 58, section II, of BuShips *Manual.*

13. Place the heavy shaft so that the smaller shaft lies in a straight line, with no short bends. Grease the large cable by means of a grease cup (8 to 10 shots), and connect by plugging the tube cleaner motor cord to the lighting circuit. After each 15 minutes of operation, more grease should be added to the large cable.

14. Examine the scale, select the proper cleaning tool (cutter bit, expanding wire brush, or vibrating head) from the small tool box, and proceed to clean the 3/4-inch

tubes. (The flexible shaft can be set to operate at two speeds: 1725 and 3450 rpm. To set the speeds or adjust the belt tension, pull out the small handle and turn the eccentric to loosen the belt. Place the belt on the desired pair of pulleys and turn the eccentric in the opposite direction to tighten the belt, and replace the handle to lock the eccentric. Do not adjust the belt tension too tightly, but allow slack so that the belt can slip if the cleaning tool becomes jammed in the tube. Be sure to replace the belt guard.)

Three accessories are provided for cleaning the 3/4-inch tubes, the choice of which depends upon the nature of the deposit in the tubes. The cleaning tools are the carbide-tipped cutter bit, the expanding wire brush, and the vibrating head.

The carbide-tipped cutter bit is the best and quickest method used to remove hard scale formed, during normal operation, from using untreated sea water feed. This tool, which cleans approximately three tubes per minute, should be used at 3450 rpm. When using this tool, the tubes must be full of water.

The expanding wire brush will readily remove soft scale generally formed from treated sea water feed. It will also remove hard scale if worked up and down the tube for a sufficient time. The expanding brush, which cleans about three tubes per minute if the scale is soft, should also be used at 3450 rpm. If the scale is hard, it may take 45 seconds or longer to clean each tube. When using the expanding wire brush, the tubes must either be full of water or a stream of water must be flowing down the tubes.

The vibrating head must always be attached to a flexible holder. It will remove any type of deposit and may be used with the tubes full of water or completely dry. The vibrating head must be used when it is impossible to clean the tubes in the presence of water. This tool should also be used at 3450 rpm and, depending upon the type of scale, will require 30 seconds to 2 minutes to clean

each tube. After the vibrating head has been used, the tubes must be polished with the expanding brush.

The evaporator tube cleaning outfit is illustrated in figure 12–5.

To clean $\frac{3}{4}$-inch tubes with the cutter bit, see that the tubes are full of water, and then proceed as follows:

1. Attach the cutter bit to the end of the small shafting. (The cutting edges of this bit are tipped with tungsten carbide which is quite brittle. Do not drop bit or strike the cutting edges on metal surfaces.)

2. Start the motor and proceed to clean the tubes by passing the bit once through each tube. With the motor off, place the end of the bit gently in the top of a tube. Place your hand on the cable about 6 inches from the back and line it up exactly with the tube. Start the motor and let the bit feed itself into the tube until the entire bit has entered. Now exert pressure and pass the bit through the tube. The clamp on the cable should be set back $16\frac{1}{4}$-inches to serve as a guide for indicating when the bit has reached the farther end of the tube. Withdraw the cable and bit slowly, and stop the motor just before the tube is withdrawn; then go to the next tube and repeat the procedure. (Three tubes should be cleaned per minute, and one bit should clean the evaporator several times.)

3. If the cutter bit fails to turn while the motor is running, the shear pin is probably broken. In this case, remove the housing from the end of the casing (left-hand thread), and replace the shear coupling.

4. If the bit jams, stop the motor immediately and free the bit. If the bit continues to jam, mark the tube and proceed to the next one. After the remainder of the tubes have been cleaned with the cutter bit, clean the marked tubes with either the expanding brush or the vibrating head.

5. Secure the motor after all the tubes have been cleaned, unscrew the bit, dry, oil, and replace the bit in the box.

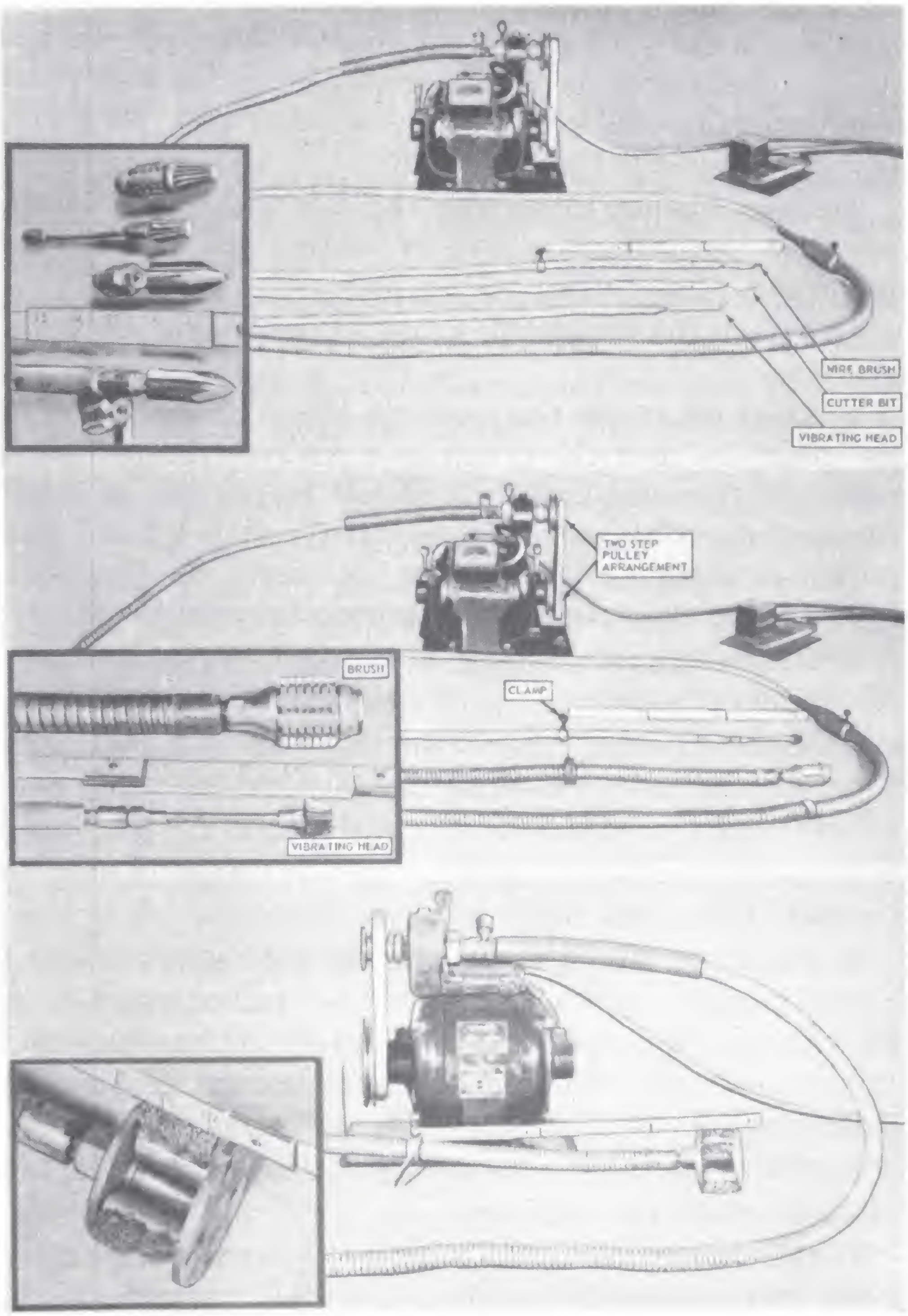


Figure 12-5.—Tube cleaning outfit.

If the small cable becomes hot while cleaning the tubes with the cutter bit, it should be greased. At any rate, the cable should be greased at least once every hour of continuous use. To grease the smaller cable, remove the flexible shafting from the inner casing and, as it is reassembled, wipe with grease. If the large cable runs hot, add more grease to the grease cup.

To clean $\frac{3}{4}$-inch tubes with the expanding wire brush, see that the tubes are full of water, and proceed as follows:

1. Attach the expanding brush to the end of the small shafting.

2. Start the motor and work the brush up and down in the tube; see that the brush goes entirely through each tube. If the scale is soft, it should be possible to clean two or three tubes each minute. If the scale is hard, one minute or more per tube may be required. See that each tube is completely clean before proceeding to the next one.

3. Remove the expanding brush, dry, oil, and replace the brush in the box.

To clean $\frac{3}{4}$-inch tubes with the vibrating head, the tubes may be full of water or dry, and the following procedure used.

1. Attach the flexible holder and the vibrating head to the end of the small shafting.

2. Start the motor and work the tool slowly up and down the tube. Each tube should be cleaned completely, as with the other tools. Depending on the hardness and the type of scale, a minute or more may be required to clean each tube.

3. Polish the tubes with the expanding brush, after the vibrating head has been used.

If it becomes necessary to clean $1\frac{3}{4}$-inch O.D. heater tubes and the inside of the overflow pipe, the scale should be removed in the presence of water. To clean these tubes, the following procedure should be used:

1. Select the vibrating head and flexible holder for the $1\frac{3}{4}$-inch tubes and attach to the end of the small shafting. (Use a cleaner shaft speed of 3450 rpm.)

2. Locate a clamp on the large shafting to indicate when the vibrating head is entirely through the tubes. Measure the distance to the end of cutter bit along the tube.

3. Start the motor and work the vibrating head slowly up and down the heater tubes until all the scale is removed.

4. Clean the inside of the overflow pipe in the same manner as the heater tubes were cleaned.

5. Disassemble the overflow piping between the evaporator and the heat exchanger. (Straight sections of 1-inch or $1\frac{1}{2}$-inch ips piping may be cleaned with the vibrating head for the $1\frac{3}{4}$-inch heater tubes attached directly to the small shafting. Elbows or bends in the 1-inch ips pipe, and sections of $\frac{3}{4}$-inch ips piping may be cleaned with the $\frac{3}{4}$-inch vibrating head. Water must flow through the section of the pipe being cleaned; otherwise the head will become clogged with scale.)

6. Remove the vibrating head, the flexible holder, and the small shafting. Dry, oil, and replace the vibrating head and the flexible holder in the box.

7. Attach the $1\frac{3}{4}$-inch expanding brush directly to the end of the large shafting, and polish the heater tubes.

8. Remove the expanding brush, dry, oil, and replace in the box.

To clean the 4-inch tube located in the center of the evaporator, proceed as follows:

1. Drain the water from the unit. If the flow stops before draining is complete, clear and drain the line with a piece of wire.

2. Connect a hose to the ship's water supply and place the end inside the evaporator. Allow a small stream of water to go down the sides of the 4-inch tube. (Do not clean the center tube when it is full of water.)

3. Attach the large expanding brush to the end of the large shafting.

4. Remove the belt guard and set the belt for the lower shaft speed (1725 rpm).

5. Place the clamp on the sleeve of the large cable so that the brush cannot come out of the lower end of the tube.

6. See that the motor is off. Then place the brush in the large tube. Start the motor and work the brush up and down the tube, being careful that the brush does not come out of the tube at either end while the motor is running. Secure the motor before removing the brush from the tube.

7. Remove the large brush, dry, oil, and replace it in the box. Disconnect the large shafting, dry, oil, and replace in the tube cleaner box. Do not coil the shafting too tightly; use the full width of the box for the coils. Replace the motor and the other parts.

After all the tubes have been cleaned, proceed as follows:

1. Remove the 4-inch handhole plate, remove the accumulated scale by hand, and flush out thoroughly (from the bottom head).

2. Replace the handhole plate, the overflow tube with the funnel, the inside feed connection, and the manhole cover.

3. Replace the electric heaters, and reconnect the wiring.

4. Reassemble the overflow piping, and install the insulation over the manhole and the bottom plate.

5. Disassemble, clean, and reassemble the rotameters, the manometer, and the flow-control valve.

Under normal conditions, tubes must be cleaned every 250 hours of operation by the sodium acid-sulfate method or every 500 hours by the mechanical method. (Operation in some waters may require more frequent cleaning.)

The sodium acid-sulfate method requires minor piping changes and some additional equipment which is not

issued by the Bureau of Ships. When this method is used, it will effectively remove scale from all surfaces coming in contact with either the salt water feed, or the brine overflow. These are the surfaces likely to require cleaning.

Cleaning with the sodium acid-sulfate solution is simple and quick as compared with the mechanical cleaning methods, and can be carried out without dismantling the unit. When using the sulfate method, the unit must be in normal operation, the only difference being that the cleaning agent is used in place of the sea-water feed. (Hydrochloric acid-cleaning of the Model X–1 unit is prohibited.)

When the evaporator is to be cleaned with sodium acid-sulfate solution, the following procedure is recommended:

1. Install a valved intake, for the solution, on the sea-water suction line to the feed pump.

2. Install a valved branch on the distillate line between the heat exchanger and the distillate tank (on submarines), or on the distillate pump discharge (on surface vessels), to discharge the distillate to the brine-collection tank (submarines) or direct to the acid-mixing tank (surface vessels).

3. In submarines, install a valved branch on the brine-collection tank so that the combined distillate and brine can be discharged by air pressure into the acid-mixing tank. On surface vessels, install a valved branch on the discharge line of the brine overboard pump so that the brine is discharged to the acid-mixing tank.

4. Locate near the distilling unit, at a level which will ensure satisfactory flow to the feed pump suction, a 25–35 gallon copper (or other nonferrous materials), acid-mixing tank equipped with a bottom discharge line, including a fine mesh screen and a valve.

5. Connect with a rubber hose (removable installation), or ½-inch pipe (permanent installation), the bottom outlet of the mixing tank and the acid intake on the feed pump suction.

6. Run similar connections from the branch on the brine-collection tank (submarines), or from the branches on the distillate and brine overboard pumps (surface vessels), to a screen thimble suspended in the open top of the acid-mixing tank.

7. Calculate the quantity of sodium acid-sulfate (nitre cake or sodium bisulfate, stock number 51–N–385, Catalogue of Navy Material, General Stores Section) by using the following formula:

Sodium acid-sulfate (pounds) required equals the capacity of the unit (gph) times 4/5.

8. In submarines, switch the distillate discharge to the brine-collection tank.

9. With the acid intake valve on the feed-water line closed, blow from the brine-collection tank (submarines), or discharge from the brine overboard pump (surface vessels), into the acid-mixing tank, ½ gallon of water for each pound of sodium acid-sulfate calculated by the above formula. Any other source of fresh or salt water may be used.

10. Dissolve the calculated quantity of sodium acid-sulfate in the measured water in the mixing tank. Stir with a wooden paddle until the sulfate is dissolved.

11. With the distilling unit in normal operation and the distillate and brine overboard discharging to the brine-collection tank (submarines), reduce the feedwater rate by approximately 50 percent and rebalance the unit. See that the hose or pipe from the mixing tank to the feed pump suction is full of acid solution and free of air.

12. Switch the feed pump suction from the regular sea-water supply to the acid mixture in the mixing tank. Wait until about 20 gallons of distillate-brine have been discharged to waste (overboard), and then shift the distillate brine discharge to the mixing tank.

13. Maintain the steam chest pressure in the evaporator at approximately 4 psi, by using the vapor compressor bypass valve, and circulate the acid mixture (from

the mixing tank) through the heat exchanger and evaporator for about 1½ hours.

14. Switch the feed pump suction to the regular water supply, and switch the brine discharge to overboard. Discharge the distillate to waste for at least one hour; by that time the distillate should then be of acceptable purity.

15. Restore to normal operation. If the compressor discharge pressure remains high, it indicates that the still has not been thoroughly cleaned. In this case, repeat the cleaning procedure, using a fresh charge of sodium acid-sulfate.

The sodium acid-sulfate mixture used in the above cleaning process is only mildly acidic and will not harm the skin or clothing. However, when working with the mixture, normal safety precautions must be taken to prevent it from coming in contact with the eyes.

The sodium acid-sulfate method of cleaning does not readily remove deposits of calcium carbonate or sulfate. However, the majority of scale formed in vapor compression distilling plants is magnesium hydroxide, which is easily removed. It may be necessary, at infrequent intervals, to remove the carbonate or sulfate deposits manually.

Because of the higher water temperature surrounding the electric heaters, the heavier scale deposit may not be readily dissolved by the sodium acid-sulfate solution. Therefore, any scale found on the electric heaters should be removed manually.

CLEANING THE HEAT EXCHANGER. The heat exchanger should be cleaned after each 200 hours of operation, and MUST be cleaned after each 250 hours. Three men are generally needed to clean a heat exchanger: one to operate the tube cleaner, one to operate the motor switch, and one to handle the water nozzle.

In cleaning heat exchangers (AA or AAA types), the following procedure should be observed:

1. Remove the cover plates from both ends. It is necessary to remove the nuts from all studs before trying

to remove the covers. However, it is not necessary to break the gasketed joint between the small inlet end cover plate and the inlet end cover. (The small inlet end cover plate should NOT be removed, except after 4000 hours.)

2. Connect the tube cleaning motor and the flexible shafts, as described in the section dealing with the cleaning of $\frac{3}{4}$-inch O.D. evaporator tubes. Connect the water hose with the nozzle, shown in figure 12–6, attached.

3. Examine the scaled tubes and select the proper tool. The lower three or four rows of tubes in the heat exchanger will generally have a hard scale deposit. (The carbide-tipped cutter bit is the best and quickest tool to remove a hard scale; it should be used in these tubes.) The upper five or six rows of tubes in the heat exchanger will usually have a comparatively soft and slime-like scale. (The expanding wire brush should be used for this type of scale.)

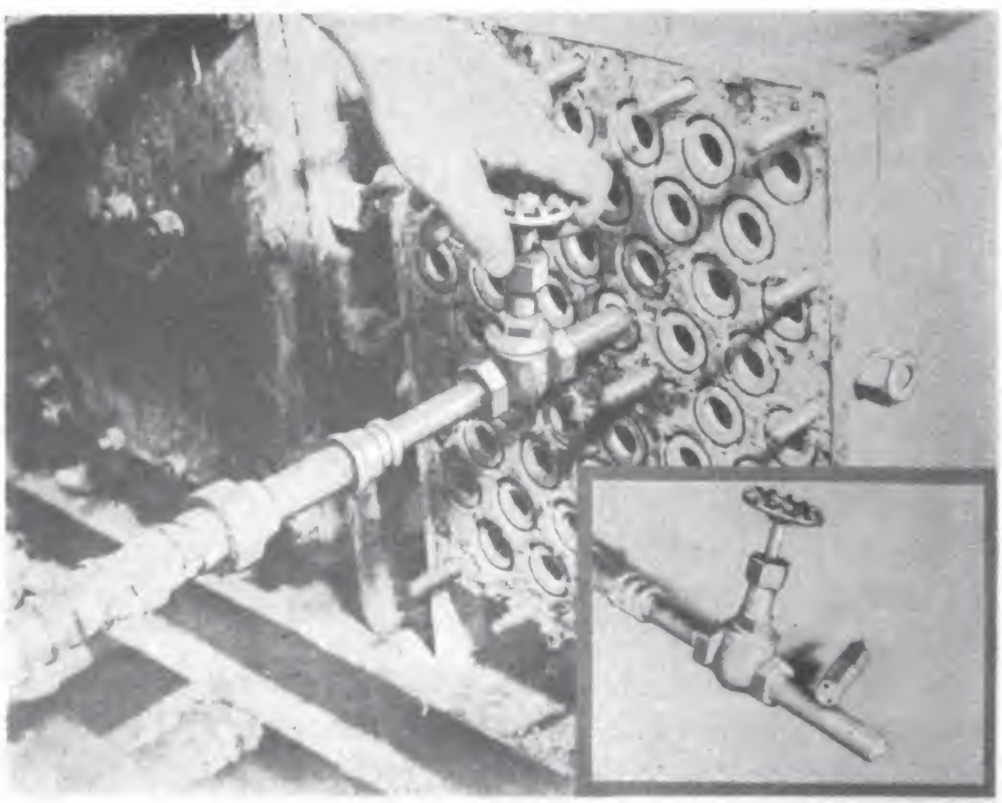


Figure 12–6.—Water nozzle.

4. Insert the hose nozzle in the end of the heat exchanger tube at the less accessible end, and pass a small stream of water through the tube.

5. Place the proper tool or the flexible shaft and position the clamp in such a place that it prevents the tool from traveling out the far end of the tube.

6. Operate both the cutter bit and the expanding brush as explained previously for cleaning the evaporator tubes. Withdraw the hose nozzle from the farther end of the tube just before the cleaning tool reaches the end.

7. If the bit jams, stop the motor, free the bit and start again. If the bit still jams, mark the tube and go on to the next, finally cleaning the marked tubes with the vibrating head or expanding wire brush. (If the bit fails to rotate while the motor is running, the hexagonal shear pin is probably broken and should be replaced.)

8. Remove the brine overflow connection at the bottom of the heat exchanger, and clean the pipe.

9. Dry, oil, and replace the tube-cleaning equipment in the box. Disassemble and grease the 9-foot shafting before replacing it in the box.

10. Reconnect the brine piping, clean the gasket surfaces of the cover plates, and replace the cover plates.

MAINTENANCE OF TUBE-CLEANING EQUIPMENT. After considerable use, the wires of the brushes tend to lay over. The efficiency of such brushes may be renewed by removing the cartridges and turning them so that the bent wires extend in the direction of rotation. This procedure may be repeated until the cartridges are no longer serviceable; then the cartridges should be replaced.

In 4-inch and in 6-inch brushes, the removal and insertion of cartridges are accomplished by unscrewing the adapter at the rear end of the individual brush, lifting out of the plate, removing and inserting the brushes.

On the brush used for $1\frac{3}{4}$-inch tubes, the cartridges may be removed by unscrewing the rear adapter. Cartridges should be withdrawn and turned or renewed one at

a time, so that those remaining in the brush will hold the spring-loaded expansion cones in place. Removal of all cartridges at once permits the cones to move to a position where considerable manipulation will be required to replace them.

The cartridges in the $3/4$-inch brush may be removed by taking off one of the snap rings, at either end of the brush. Since the brush has no internal expanding mechanism, there is no specified procedure.

There are times when cutter bits have to be resharpened. A hone provided in the tube cleaner box is used to sharpen the tungsten carbide cutting edges of the bits. When the bit cannot be sharpened by the hone, grinding is necessary.

When grinding cutter bits, the following precautions should be observed:

1. Each flute of the cutter bit must be ground separately.
2. Grind only the cutting edges, not the diameter, and maintain the 15° relief angle.
3. Never allow the wheel to become loaded; keep it clean.
4. Keep the bit in motion while passing the wheel, avoiding any stationary contact of the bit against the wheel.
5. See that the flutes are carefully indexed and ground so that each flute will do the same amount of cutting.

SUMMARY

A good preventive maintenance program should be carried out to ensure trouble free performance of the distilling plants. Therefore, you must know how to remove scale from evaporator tubes. In addition, you will be required to test evaporators and condensers for salt water leaks.

QUIZ

1. If the normal amount of steam at the proper pressure is not supplied to the plant, what trouble results?
2. What first-effect tube nest pressure range should be maintained within a distilling plant?
3. Why should the vacuum in the first-effect tubes be maintained as high as possible?
4. What 5 primary factors affect the first-effect tube nest vacuum?
5. What kind of losses will be caused by air leaks from the steam side of the first-effect tube nest to the first-effect shell space?
6. If an air leak in the first-effect tube nest is suspected, what should be done?
7. What causes an accumulation of air in the evaporator tubes, or an excessive loss of tube nest steam to the distilling condenser?
8. Why should the operation of the distilling plant with shore-water feed be kept to an absolute minimum?
9. If the brine concentration is too high, what will result?
10. If it is difficult to maintain the proper brine density, what should be done?
11. What is the purpose of using the cornstarch and boiler compound solutions for treating evaporator feed water?
12. What takes place when steam is admitted into the tubes when chill shocking a plant?
13. If the cornstarch and boiler compound feed treatment is not used, how often should the distilling plant be chill-shocked?
14. Most of the operating troubles of a low-pressure submerged-tube distilling unit can be traced directly to what source?
15. What are the most common causes of air ejector troubles?
16. The last-effect shell pressure is directly dependent upon what factor?
17. When are scale deposits inside distilling condenser tubes unlikely to occur?
18. What is likely to result when salt water leaks into the vapor or the fresh water spaces?
19. If there is an air leak in a heat exchanger, how may the defective tubes be located?
20. Under normal conditions, the retubing of heat exchangers should be accomplished by what activity?

21. The method used to clean the inside surface of the heater and the condenser units depends upon what factor?
22. When scale formation is so heavy that the first-effect tube nest vacuum approaches zero, how will the capacity be affected?
23. When a low-pressure distilling plant is operating properly and the feed water has been treated, what is the recommended interval between cleanings?
24. When large tube bundles are to be mechanically cleaned, how should they be removed from evaporator shells?
25. Why should a torch never be used for descaling a tube nest made up of straight tubes?
26. On submarines and on small Diesel-driven surface vessels, where the absence of any steam supply necessitates some other source of heat supply for the evaporating process, what type of distilling plants are used by the Navy?
27. Compared with the Model X—1 unit, what are the disadvantages of using a Model S unit?
28. When a Model S unit is secured, the still should be flushed, in accordance with manufacturer's instructions, for how long a period?
29. When is it permissible to clean Model S distilling units by circulating a cold solution of hydrochloric acid in water, through the distilling plant?
30. If a Model S distilling unit is to be cleaned by completely dismantling the tube nest assembly, how should the scale be removed?
31. Under normal operating conditions, how often must the evaporator of a Model X–1 distilling unit be cleansed mechanically?
32. What three cleaning tools can be used to clean ¾-inch O.D. tubes?
33. If an expanding wire brush is used to remove soft scale from ¾-inch tubes, how many tubes can be cleaned each minute?
34. Under normal operating conditions, if the sodium acid-sulfate method is to be used to clean evaporator tubes, how often must the tubes be cleansed?
35. If a cutter bit cannot be sharpened by the hone, which is provided in the tube cleaner box, what process will be necessary?

CHAPTER 13

MAINTENANCE OF REFRIGERATION EQUIPMENT

In addition to other major responsibilities as an EN2, you will be responsible for the maintenance and repair of specific refrigeration equipment. From your previous study and experience, you should be familiar with the basic theory of refrigeration and have an understanding of the mechanical refrigeration cycle. If you need to refresh your memory on these subjects, refer to the refrigeration section in the Navy Training Course, *Fireman,* NavPers 10520–A.

This chapter deals primarily with the maintenance of refrigeration equipment, giving special emphasis to compressors, condensers, safety cutout devices, piping, and valves.

COMPONENT PARTS OF A REFRIGERATION SYSTEM

In order to be able to repair and maintain refrigeration equipment properly, you should know how each of the component parts of the system functions. Since Freon-12 is the refrigerant used most extensively on naval vessels, this chapter deals specifically with the Freon-12 plant.

Evaporator

The evaporator is nothing more than a coil of copper alloy tubing installed inside a refrigerated space. The liquid Freon–12 begins to vaporize as it enters the evaporator from the expansion valve. The surrounding space and substances furnish the heat of vaporization to the

Freon–12 as it circulates through the evaporator tubing. This causes the refrigerant to boil, changing it to vapor.

In normal practice, the Freon is entirely vaporized by the time it reaches the end of the evaporator coils, and while passing through the latter portion of these coils the Freon is superheated approximately 10° F. This superheat, kept fairly constant by the action of the expansion valve, eliminates the wetness from the saturated Freon vapor and prevents the possibility of carrying liquid over into the compressor. In addition, superheating increases the efficiency of the plant's operation.

Compressor

The function of the compressor is to withdraw the gaseous refrigerant from the cooling coils of the evaporator and deliver it to the condenser where its heat load can be absorbed by the cooling water. The compressors employed in Freon–12 refrigeration systems are usually of the multicylinder, vertical, *V* or *W* enclosed, single-acting reciprocating type, and driven by an electric motor. (The motor has a V-belt or direct connection with the compressor crankshaft.) Cross-sectional assembly views of typical compressors are shown in figures 13–1 and 13–2.

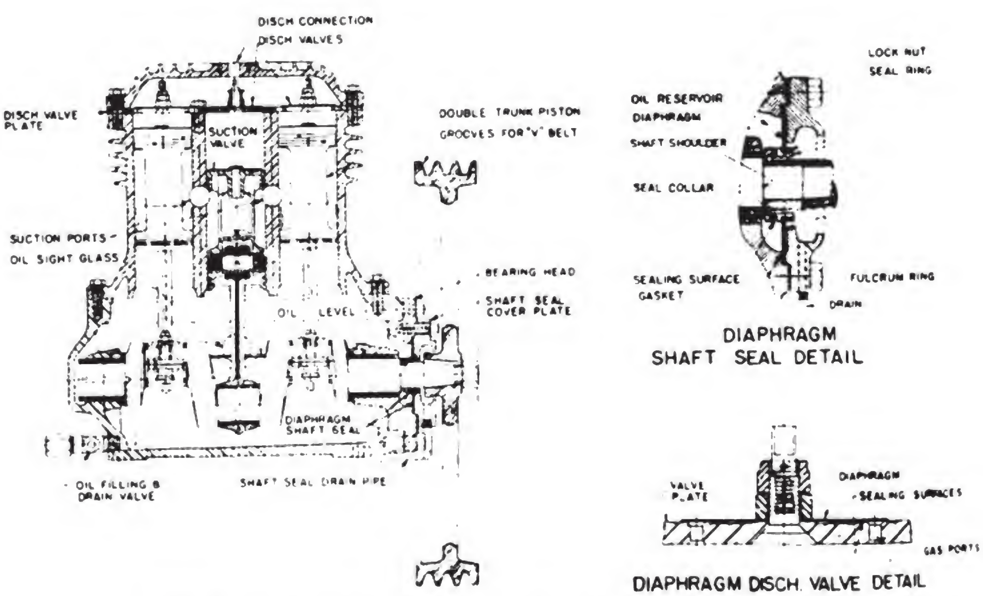


Figure 13–1.—Cross-sectional view of a diaphragm seal.

The compressor shown in figure 13–1 is equipped with double trunk pistons and integral suction valves, while the compressor shown in figure 13–2 is provided with single trunk pistons. The suction valves of the latter type compressor are separately located between the cylinder head and block. Both types of valves permit the entrance of refrigerant suction vapor directly to the cylinder block.

SUCTION AND DISCHARGE VALVES.—The compressor suction and discharge valves are generally of the diaphragm type (figure 13–1), or of the ring plate type. In the

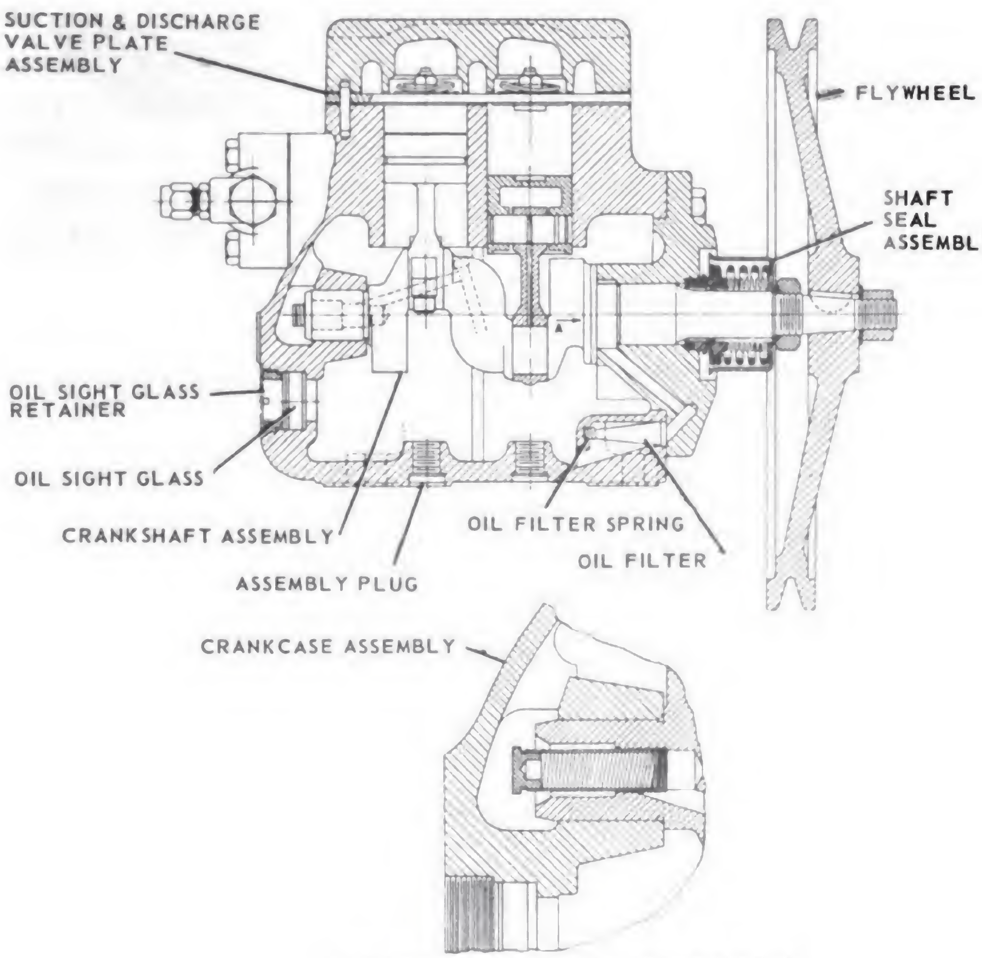


Figure 13–2.—Typical refrigeration compressor-sectional details.

diaphragm type, the inherent spring of the thin disk is sufficient to provide quick closing of the valves. The ring-plate type has auxiliary springs to provide the necessary pressure between the valve ring and the sealing surfaces on the piston top or discharge valve plate.

LUBRICATION SYSTEM.—Freon–12 compressors may be provided with either forced feed lubrication or splash lubrication. In the latter case, the oil level maintained in the compressor crankcase is relatively high and no oil pump is provided. Splash lubrication is perfectly satisfactory for small Freon–12 compressors (figure 13–1). Most large Freon–12 compressors, however, are provided with oil pumps and full-pressure lubrication (figure 13–2). The operating level of the lubricating oil in the compressor is indicated on a sight glass installed in the side of the compressor crankcase.

CRANKCASE SEALS.—These seals prevent leakage of refrigerant and lubricating oil from the system. Freon–12 compressors furnished for naval vessels are provided with metallic crankshaft seals at the flywheel or pulley end of the crankshaft.

One type of shaft seal is a bellows assembly (figure 13–2), in which a hardened steel seal collar fits against a shoulder; there is a special rubber-like packing between the collar and the shoulder. The seal ring is held in position by a flexible metallic bellows and is pressed against the shaft seal collar by means of a spring.

The diaphragm type of shaft seal is illustrated in figure 13–1. The thin, metallic diaphragm arrangement provides a balancing effect with respect to the fulcrum ring, and this ensures that the pressure on the seal surfaces will be practically constant with varying compressor crankcase suction pressures.

Condenser

The compressor discharge line terminates at the refrigerant condenser. The WATER-COOLED CONDENSER, illustrated in figure 13–3, is generally used for shipboard

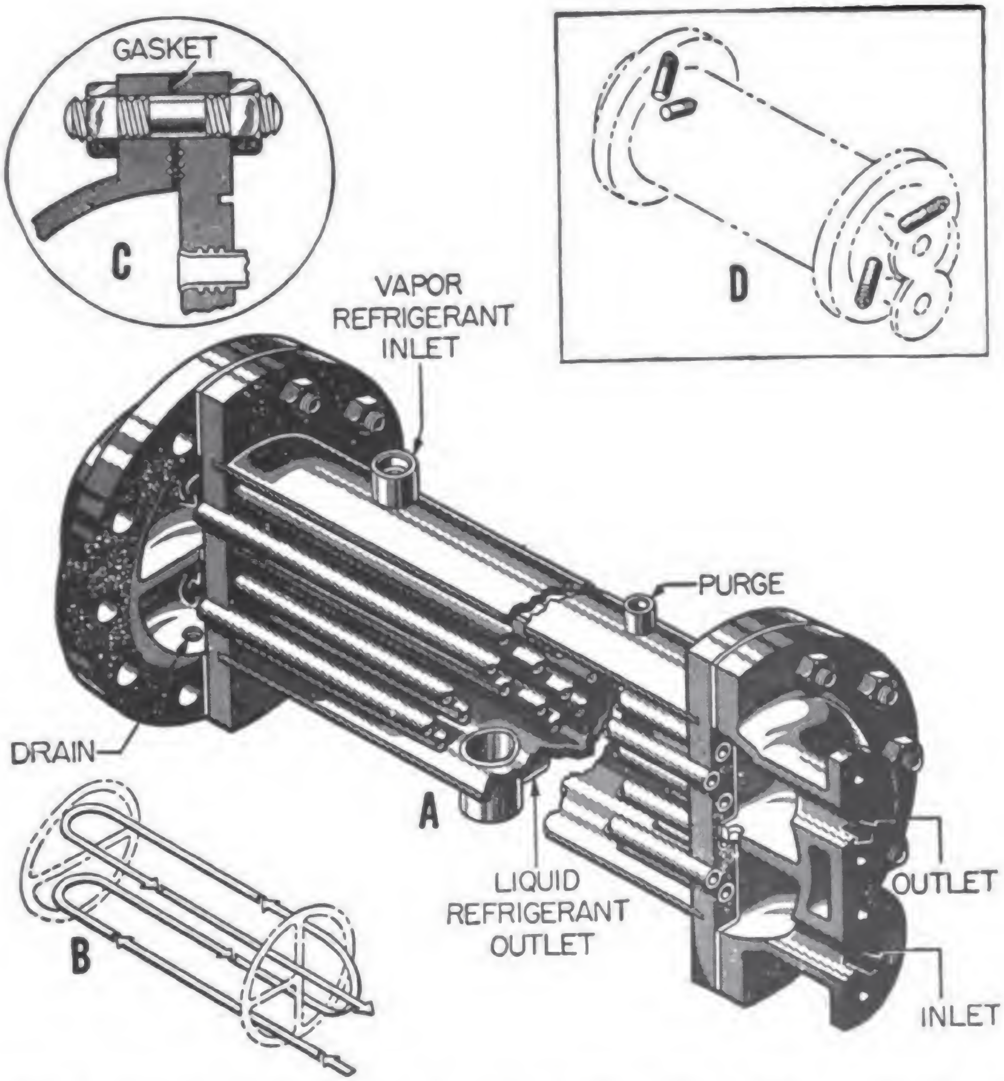


Figure 13–3.—Freon condenser: (A) longitudinal cutaway view, (B) water-flow diagram, (C) arrangement of head joint, (D) position of zinc fingers.

Freon–12 installations. These condensers are of the multipass shell-and-tube type, with circulating water flowing through the tubes. The water-cooled condenser is constructed with the tube sheet soldered to the shell and the tubes rolled in the tube sheet. (Bare tubes are generally provided.) The tubes are expanded into grooved tube sheet holes to make an absolutely tight joint between the refrigerant in the shell and the circulating water. Refrigerant vapor is admitted to the shell, and condenses on the outer surfaces of the tubes.

Any air which may accidentally enter the refrigeration system will be drawn through the piping and eventually discharged into the condenser with the Freon-12 gas. Since air is lighter than the Freon-12 gas, it will rise to the top of the condenser when the plant is shut down. A purge valve, for purging accumulated air from the refrigeration system when necessary, is installed at the top of the condenser, or at a high point in the compressor discharge line.

Although the large Freon-12 plants are equipped with water-cooled condensers, small self-contained units are commonly provided with AIR-COOLED CONDENSERS; this eliminates the necessity for circulating water pumps and piping. The air-cooled condensers consist of tubing provided with external fins which facilitate the transfer of heat. With this type of condenser, fans are provided to ensure positive circulation of air for carrying away the heat of condensation.

Receiver

The receiver, illustrated in figure 13–4, serves as a temporary storage space for the liquid Freon flowing from the condenser. This temporary storage allows any vapor from the condenser, carried along with the liquid, to condense before reaching the expansion valve. In addition, the receiver acts as a seal between the vapor in the condenser and the flow of liquid to the expansion valve.

The receiver is a plain cylindrical tank, with dished heads and the liquid inlet is at the top, near one end. The outlet line, near the other end, extends down into the receiver, leaving ½ inch free space between the outlet opening and the bottom of the receiver. A baffle plate, reaching halfway up the shell and with about ½ inch free space at the bottom, is located on each side of the interior outlet tube. This baffle minimizes any surges of the liquid, within the receiver, due to pitching or rolling of the ship. Violent surging of the liquid refrigerant would allow uncondensed gas to enter the interior outlet tube and

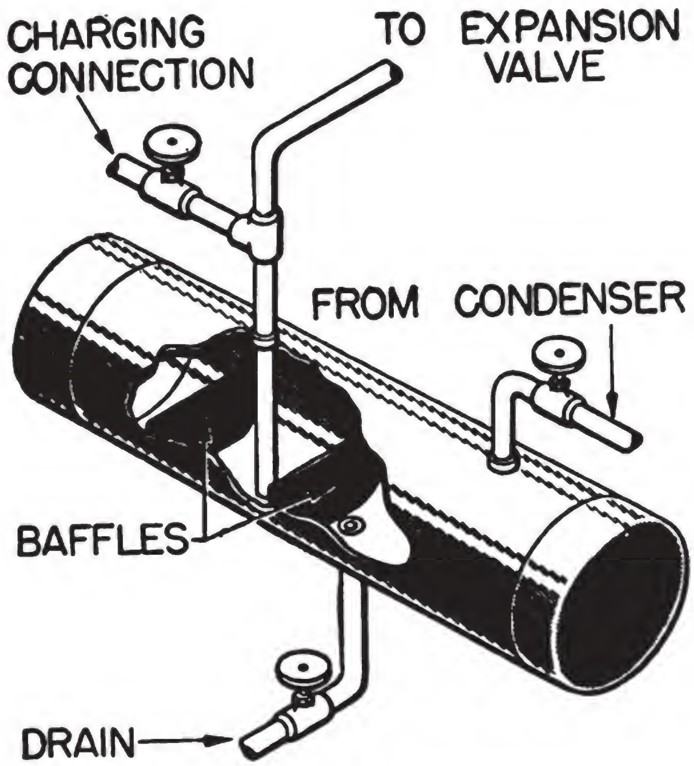


Figure 13–4.—Liquid Freon receiver.

consequently interfere with the operation of the expansion valve.

A drain valve is generally installed at the bottom of the unit to remove liquid refrigerant, as necessary, for making repairs to the system or to drain off excessive refrigerant from the system when it is inadvertently overcharged.

Piping and Valves

On modern naval installations, all refrigerant piping is made of copper tubing with forged brass or wrought copper fittings, silver-soldered or brazed. Copper pipe assures freedom from corrosion with Freon–12 refrigerant even in the presence of an appreciable amount of moisture. Once a system has been cleaned of initial dirt, copper does not contribute additional foreign matter to plug the strainers. The internal surface of copper pipe is smooth enough to minimize internal friction of the refrigerant flow.

Copper can also be shaped easily to meet installation

requirements. When the refrigeration piping system is installed, it is arranged to permit various setups for the operation of the plant. Sections or units of the entire system can be placed into operation with a complete unit of the system as a standby or spare. Sections of piping or equipment can be isolated for cleaning and repair.

REFRIGERANT STOP VALVES.—The suction line stop valve, located in the refrigerant suction line to the compressor, permits the isolation of the compressor from the remainder of the system. To guard against leakage of Freon-12 around the valve stem, special precautions are taken in the design of all refrigerant piping system valves.

The types of stop valves used by the Navy are the packed stem and the packless stop valves. The former type have conventional stuffing boxes, but the special stem packing employed is impervious to the solvent action of Freon-12. In addition, a seal cap is provided to screw over the stem, as a second seal against leakage of refrigerant. This seal cap fits on the top face of the valve body with a metallic or fiber gasket between the cap and the valve body.

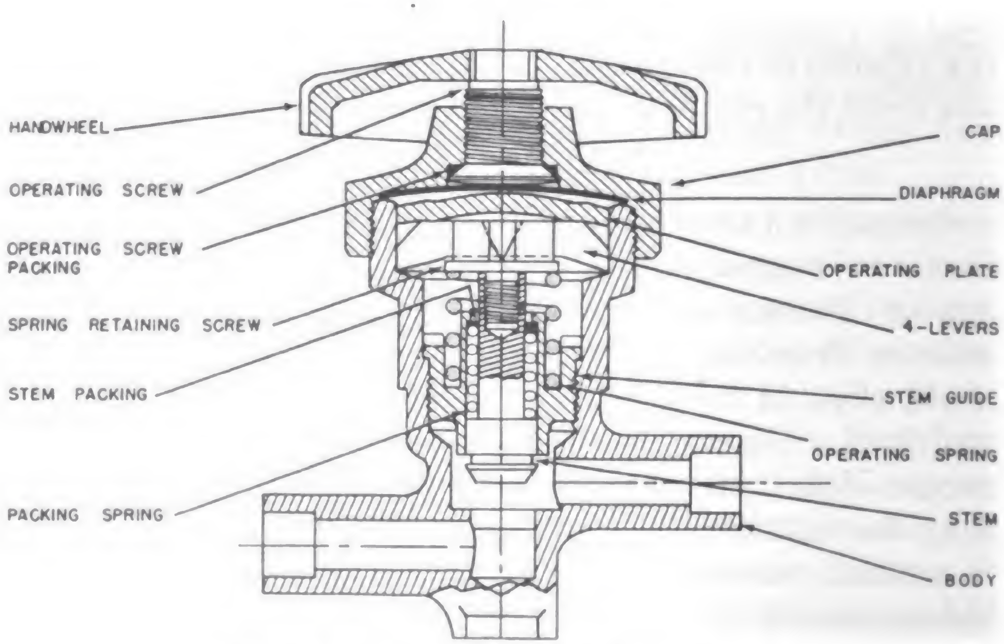


Figure 13-5.—Packless valve (diaphragm type).

A number of packless stop valves (diaphragm and bellows) are inserted in the refrigerant lines at various points. A diaphragm type valve is illustrated in figure 13–5. The valve contains a diaphragm that seals off the fluid flow chamber from the space surrounding the stem of the outside handle. The lower stem is separate and is kept in contact with the upper stem, or handle part, by a spring. The sealing diaphragm is located between the two parts.

LIQUID AND SUCTION STRAINERS.—The purpose of the liquid strainer (figure 3–6) is to remove foreign particles

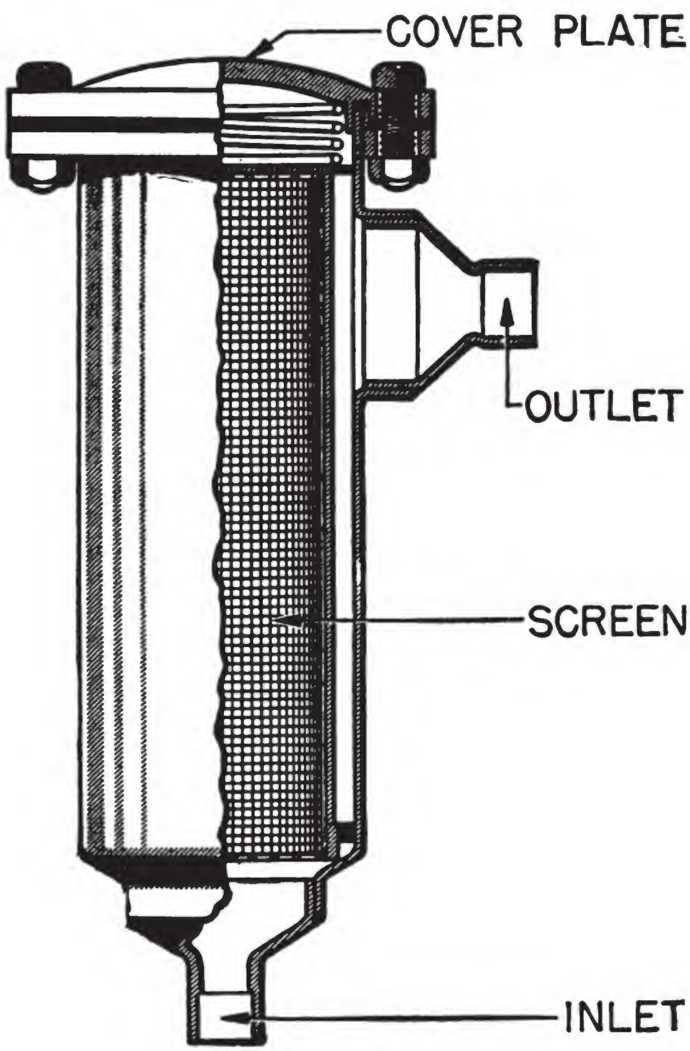


Figure 13–6.—Liquid Freon strainer.

carried by the Freon-12 liquid before it passes through the solenoid and expansion valves. In the process of installing a refrigeration system, a certain amount of foreign matter remains in the lines. Since the refrigerant piping system forms a closed circuit, particles of foreign matter will remain in the system unless trapped in a strainer or filter and removed by cleaning these units. Such foreign matter circulating through the system may clog the expansion valve orifices, or cause the automatic valve mechanisms to stick.

The suction strainer (similar to the liquid strainer), in the suction line at the compressor, serves to prevent scale or foreign matter from entering the compressor. Such foreign matter may score the compressor or system valve seats. The suction strainer body can be opened by unbolting its cap and, when necessary, the strainer screen can be removed for cleaning. The cleaning of strainers will be discussed later in the chapter.

SOLENOID VALVES.—The solenoid valve (figure 13–7) is

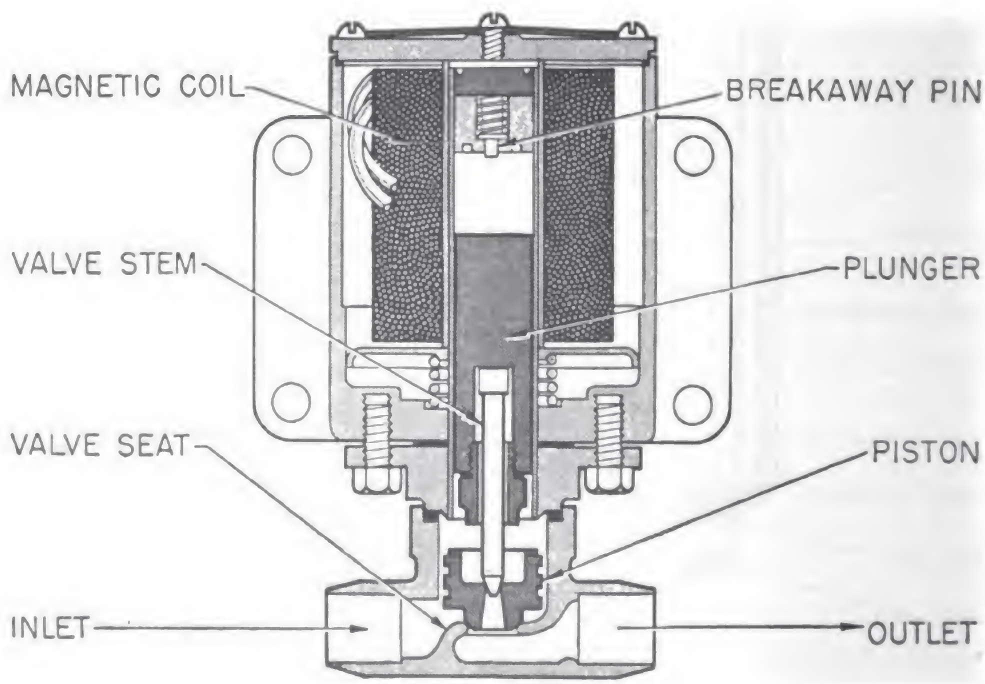


Figure 13–7.—Solenoid valve.

located in the liquid Freon line, between the strainer and the expansion valve. When the current is on, the magnetic coil of the valve is energized; this causes the plunger to lift the valve from its seat, permitting the refrigerant to flow. When any of the other control devices breaks the electrical circuit, the magnetic coil releases the plunger, instantly closing the valve and completely stopping the flow of refrigerant.

The function of the solenoid valve is to stop the flow of liquid refrigerant to the evaporator when the space being cooled has reached the desired temperature, and to open to permit flow when cooling is required. The valve is electrically energized by a thermostatic switch which is responsive to temperature changes in the space being cooled.

The thermostat mechanism contains a flexible metal bellows, one side of which communicates with the remote bulb tubing filled with a liquid similar to Freon-12. Remote bulbs for air contact operation are finned; bulbs for surface contact operation are constructed so that they can be clamped firmly against a pipe or other surface. (See figure 13–8.) The snap-off section in this thermostat is rigid, thus preventing excessive arching and ensuring long life of the contact points.

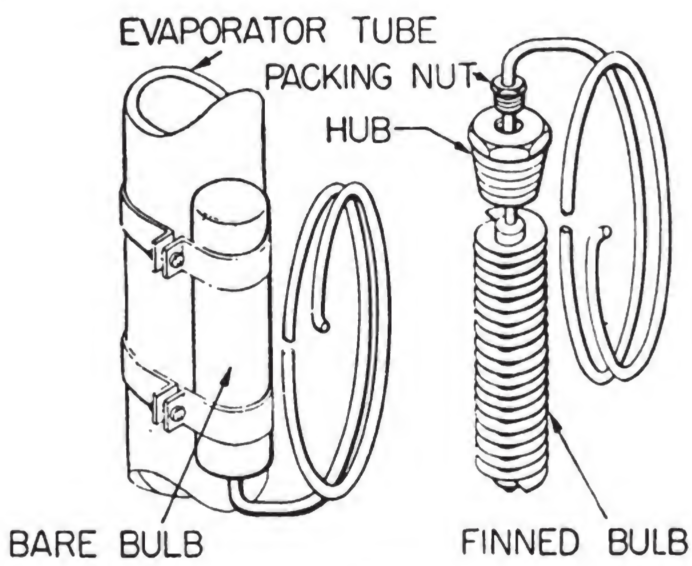


Figure 13–8.—Thermobulbs.

Another solenoid valve, located in the main liquid line, is generally installed in shipboard Freon–12 refrigeration systems. This valve, known as the KING solenoid valve, is wired to the motor controller. The function of this valve is to stop the flow of liquid refrigerant from the receiver when the compressor stops for any reason other than suction pressure control.

THERMOSTATIC EXPANSION VALVE.—This valve operates to feed into the cooling coils the amount of refrigerant necessary to keep the evaporator working at maximum effectiveness, in accordance with heat load variation, and to prevent the flooding back of liquid refrigerant to the compressor. It is also designed to maintain the refrigerant vapor leaving the cooling coils at a constant degree of superheat, regardless of suction pressure.

The amount of superheat depends on the valve spring pressure exerted on the diaphragm. For a given spring setting, the valve maintains a relatively constant degree of superheat at the coil outlet, ensuring that all the Freon-12 liquid is evaporated before it leaves the coil to return to the compressor.

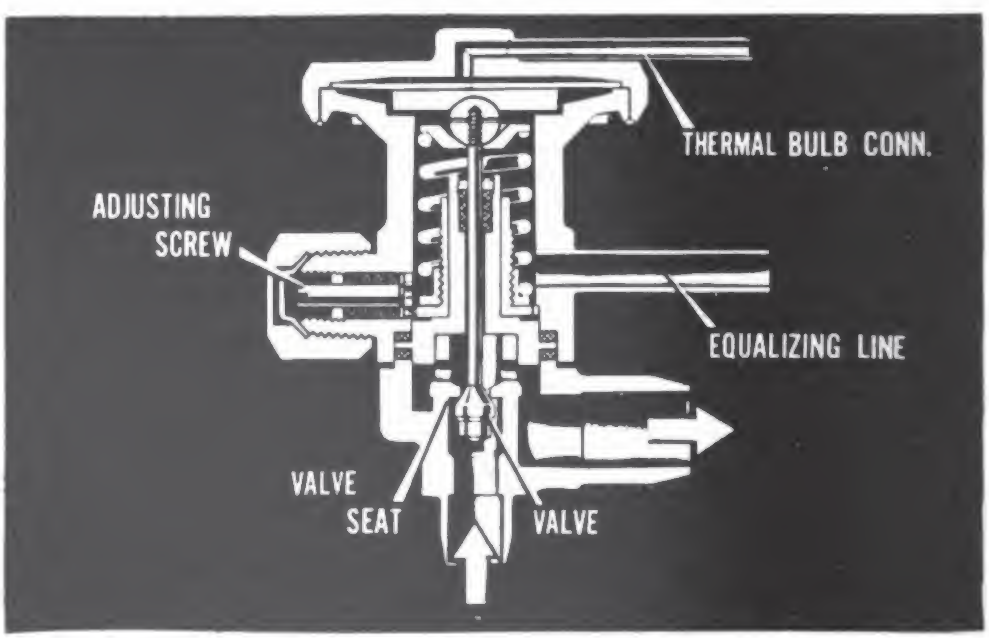


Figure 13–9.—Thermostatic expansion valve.

A cross-sectional assembly view of a thermostatic expansion valve, used aboard naval vessels, is shown in figure 13–9. The control bulb of the valve, charged with Freon-12, is clamped to the suction line near the cooling coil outlet. The temperature changes in the suction line are reflected in corresponding pressure changes within the control bulb. These pressure changes in the bulb are transmitted through the control tubing to the diaphragm of the expansion valve, which, in turn, transmits motion to the valve stem and needle. It is essential that good thermal contact be maintained between the control bulb and the bare surface of the suction line pipe.

REFRIGERANT CONTROL MANIFOLD.—A liquid-control manifold is sometimes installed to combine in one compact assembly the thermostatic expansion valve, the solenoid valve, the strainer, the hand expansion valve, the various shut-off valves, and the flanged line connections. This assembly eliminates a considerable quantity of piping and fitted joints, thereby minimizing the possibility of refrigerant leakage.

SUCTION PRESSURE REGULATING VALVE.—This type valve, illustrated in figure 13–10, is generally installed between each evaporator and the suction line, where two or more spaces serviced by a single compressor unit are maintained at different temperature levels.

The pressure regulating valve is of the adjustable spring-operated type and can be set to maintain a fixed pressure (and temperature) in the evaporator which it serves, independent of other evaporators in the system. Automatic operation, however, is maintained by diaphragm balance which permits positioning of the valve and controls the refrigerant flow.

WATER REGULATING VALVE.—A circulating water regulating valve, illustrated in figure 13–11, controls the amount of circulating water flowing into the condenser. The valve is actuated by the refrigerant pressure in the compressor discharge line which acts on a bellows or

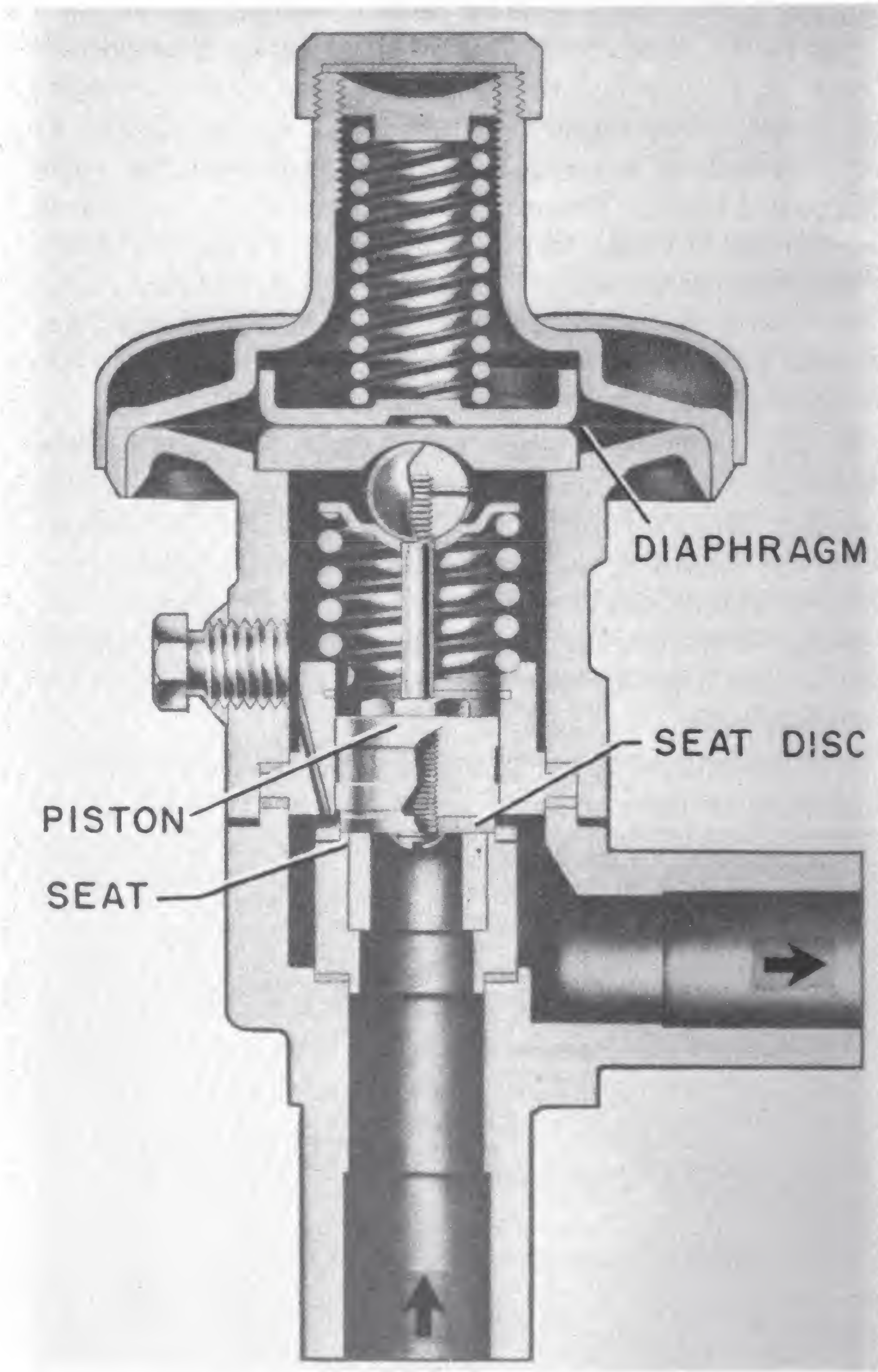


Figure 13–10.—Suction pressure regulating valve.

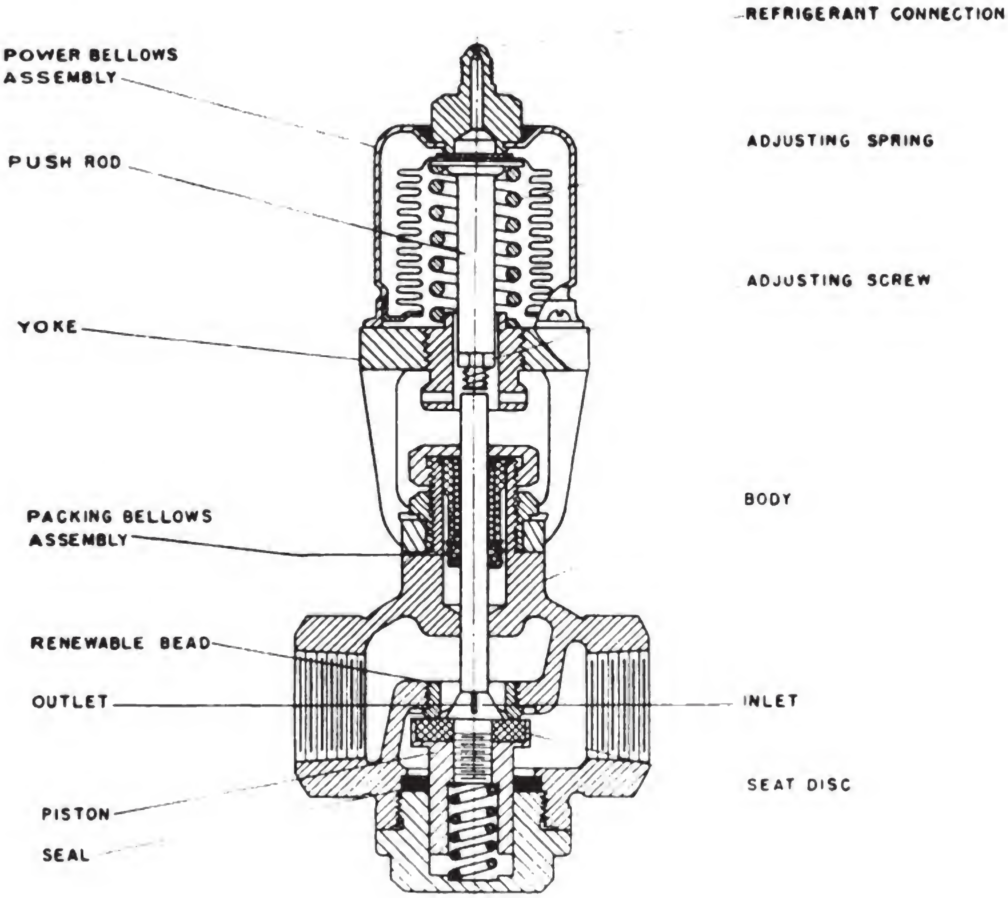


Figure 13–11.—Condenser water regulating valve.

diaphragm, communicating motion to the valve stem. As the temperature of the condenser increases, the refrigerant pressure increases beyond the pressure for which the regulator adjusting spring is set. The increased pressure causes the bellows to open the valve wider and supply additional circulating water. Conversely, when the temperature of the condenser is such that the refrigerant pressure falls below that for which the regulator adjusting spring is set, the force of the spring tension overcomes that of the refrigerant pressure acting on the bellows, thus closing the valve to reduce the flow of circulating water.

Factors tending to change the condenser pressure include:

1. A change in the temperature of the cooling water inlet.

2. A change in the heat load.
3. Scale deposits in the condenser tubing.

Under operating conditions where cold cooling water is available, a saving in power can be effected by operating at lower condenser temperatures and correspondingly lower pressures. The presence of cooler circulating water also permits the use of less water with correspondingly less erosion of the condenser tubes.

Cooling Units

Refrigeration plants are generally provided with a cooling device known as a HEAT INTERCHANGER. This device may be located in the suction line near the evaporator in low-temperature installations. It prevents carry-back of liquid refrigerant in the suction line and the flashing of liquid into gas while it is being admitted to the expansion valve; this increases the efficiency of the valve operation.

CUTOUT AND SAFETY DEVICES

The cutout and safety devices installed in the Freon-12 refrigerating plant include the low-pressure cutout switch, the high-pressure cutout switch, the relief valve, and the water-failure pressure cutout switch.

Low-Pressure Cutout Switch

In the compressor suction line between the suction line stop valve and the compressor, a connection leads to the low-pressure cutout switch (often called the suction pressure control switch). This switch is located on the compressor base or on a panel adjacent to the compressor. The refrigerant suction pressure acts on the metallic bellows of the power element of the switch and produces movement of a lever mechanism operating electrical contacts. These contacts are in a circuit connected to the compressor motor controller panel.

When all the solenoid valves have closed, the suction pressure drops until it reaches the setting of the low-

pressure cutout switch (approximately 2 psi). When the suction pressure is 2 psi, the switch opens, stopping the compressor. When one or more solenoid valves open, the suction pressure rises, causing the switch to close its contacts and start the compressor. The low-pressure cutout switch has a differential of about 18 psi; it stops the compressor when the pressure drops to 2 psi; and it restarts the compressor at about 20 psi.

High-Pressure Cutout Switch

A switch connected to the high-pressure line serves as a safety device to prevent dangerously high pressure from developing within the system. When the discharge pressure rises above 150 psi (the usual switch setting) the switch opens, stopping the compressor and shutting down the system. The switch has a differential of about 25 psi. When the high pressure decreases to 125 psi, the switch closes, and automatically restarts the compressor.

Relief Valve

This unit is also placed in the high-pressure discharge line from the compressor. The relief valve acts as a safety device when the high-pressure cutout switch fails. Set to open at about 200 psi, it prevents any further rise in pressure on the high-pressure side by bypassing the excess pressure to the suction side of the compressor.

Water Failure Switch

This switch is primarily a safety device to shut down the compressor in the event of water failure. The water pressure cut-out point is established by the corresponding static head pressure on the condenser.

To determine the cut-out point, slowly close down on the supply water valve to the condenser. The switch should cut out just before the water is completely shut off. After establishing the cut-out point, adjust the cut-in point about 5–10 psi higher than the cut-out point.

GAGES AND THERMOMETERS

The refrigeration system also includes the necessary pressure gages and thermometers for observing the pressures and temperatures at various places in the system. Figure 13–12 illustrates the dial of a Freon-12 gage. The pressure and vacuum scale is printed in black, while the corresponding temperature scale is printed in red. The wide pointer is a nonworking, or stationary, pointer that may be set manually to indicate the maximum working pressure. The gage for the suction, or the low-pressure, side has a maximum reading of 150 psi. The gage for the discharge (high-pressure) side has a maximum reading of 300 psi. Both gages read down to 30 inches of vacuum.

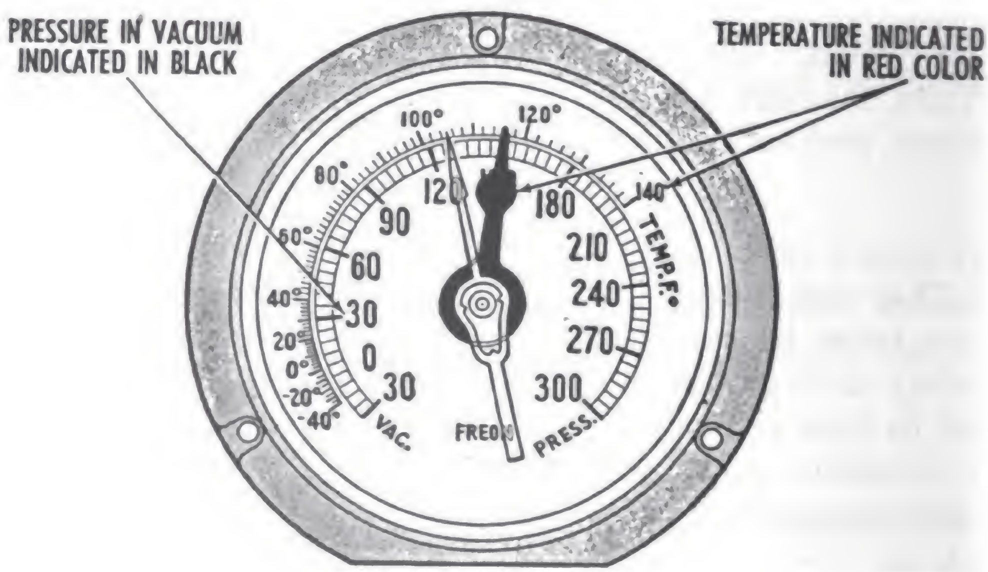


Figure 13–12.—Freon-12 gage.

The temperature scale on dial of the Freon-12 gage shows the temperatures which correspond to various saturated Freon-12 pressures. Since the gage is actuated by pressure, and a certain degree of superheat is generally present, the temperatures indicated are approximate.

MAINTENANCE OF REFRIGERATING SYSTEMS

The remainder of this chapter deals with the maintenance of the Freon–12 plant—with defrosting, testing,

and charging the refrigerant system; with pumping down the system and checking for noncondensable gases; and with the maintenance of compressors. Detailed information on maintenance and repair of refrigeration systems can be obtained from the manufacturers' instruction books, and from chapter 59 of BuShips *Manual.*

Defrosting a Refrigerated Space

As in an ordinary household refrigerator, cooling coils of the ship's refrigerated compartments gradually accumulate a covering of frost—the result of moisture in the air condensing and freezing on the coils. This frost, because of its heat insulation properties, reduces the cooling efficiency of the system and requires longer use of the compressor. Therefore, the frost must be removed frequently. The frequency of defrosting operations depends upon the rapidity of frost build up. The latter, in turn, depends upon such factors as the refrigerant evaporating temperature, the free moisture content of the materials being cooled, the temperature of the refrigerated space, and the frequency of opening the refrigerated compartment doors.

It is advisable to defrost the cooling coils before the average frost thickness reaches *3/16* inch in the average cold storage refrigerating plant installation. However, in some cases the frost layer may become appreciably thicker without seriously interfering with plant operation, while in other cases, particularly when operating in the tropics, more frequent defrosting may be necessary to maintain satisfactory operation of the plant.

The most common method of defrosting the average Freon–12 refrigerating plant installation is to shut off the supply of Freon to the box to be defrosted. This can be accomplished by closing the liquid line stop valve ahead of the expansion valve and by leaving the entrance door open, allowing the temperature of the compartment to rise above 32° F. Then the frost melts off the coils,

or may be easily brushed off. Since the coils are made of tinned copper or galvanized steel tubing, care must be taken not to injure the evaporator by scraping surfaces when defrosting.

Many Freon–12 plants are provided with HOT GAS DEFROSTING LINES to facilitate defrosting of the meat room evaporator. These lines permit defrosting of the coils without having to raise the temperature of the box above 32° F. With this system, a piping connection conveys hot vapor from the compressor to the evaporator coils. The piping branches off from the discharge line between the compressor and the condenser, passes through the wall of the refrigerated room, and connects to the suction line at the outlet of the evaporator coils, where shut-off valves are provided. The hot vapor released into the coils melts the frost in less than 30 minutes.

The defrosting process is accomplished while the system is in operation. For example, when it is desired to defrost the coils of the meat room, close the liquid supply and suction return line valves of the cooling coils. Then open the valve in the hot gas supply line. This admits the gas to the coils, where it melts the frost on the exterior of the coils; in the process the gas condenses. The condensed refrigerant is released from the coils by expanding it into the evaporator of a higher temperature box (butter-and-egg or fruit-and-egg or fruit-and-vegetable room) after the liquid supply valve to that box has been closed. After the defrosting is completed, the refrigerating system is returned to its normal operating condition. To avoid liquid slugs being returned to the compressor, care must be taken to have all liquid Freon discharged from the meat room coils before opening the suction line valve from this compartment.

Testing System for Leaks

The refrigeration system should be checked for leakage of gas at least once each month. However, you should always be on the watch for abnormal log readings

or unusual operating conditions which would indicate a shortage of refrigerant; such an indication necessitates testing the entire system for leaks. The following are symptoms of shortage of refrigerant:

1. High suction line temperatures
2. Crankcase and cylinder temperatures relatively warm, with low suction pressure
3. Liquid line refrigerant temperature too warm
4. Bubbles in the refrigerant sight flow indicator
5. Liquid refrigerant carrying partially through the coil, with considerable superheat at the thermal element location
6. Compressor running continuously
7. Excessive oil seepage at the shaft seal connection
8. Oil seepage at refrigerant system piping and compressor connections

The two methods for testing a refrigerating system for leaks are the halide torch and the soapsuds methods. The choice of method will depend, among other things, upon the size of the leak and the ventilation of the space. A halide torch should NEVER be used in magazines.

HALIDE TORCH.—The most positive method for finding leaks in Freon–12 systems is by use of the halide torch (figure 13–13). A sample of air is drawn through the exploring hose into the mixer by injector action of the fuel discharged from the fuel tank. The air-fuel mixture passes over the reaction plate, which is heated to incandescence. If Freon–12 is present, the torch flame will change from its normal blue, or neutral color, to a characteristic green color as it comes in contact with the reaction plate. The shade of green will depend upon the relative amount of Freon–12 present, being pale for light concentrations and dark for heavier concentrations. Excessive quantities of Freon–12 color the flame a vivid purple, and may even extinguish it by driving out the supply of oxygen in the air.

Of the several types of halide torches available, most

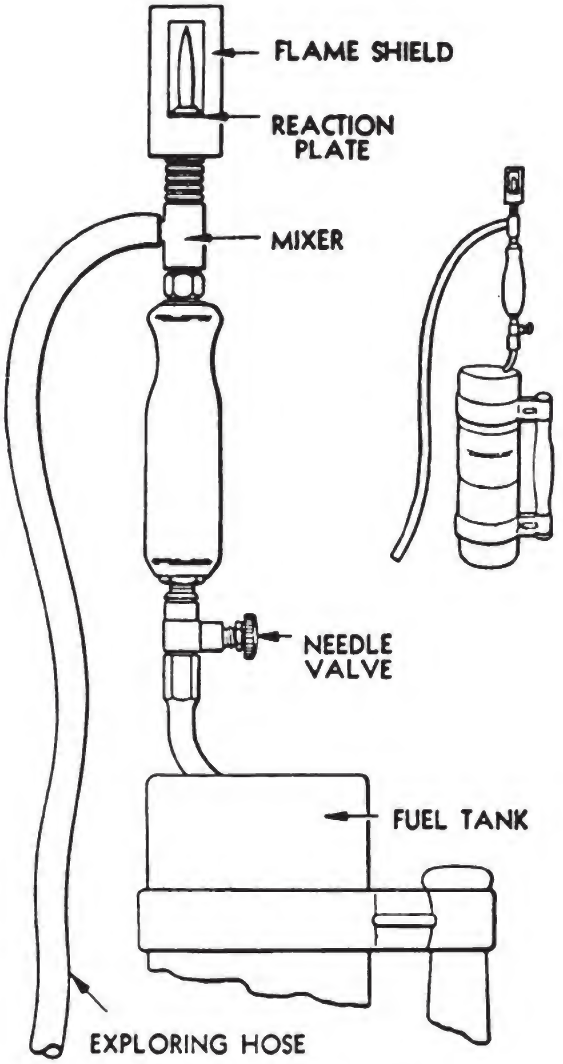


Figure 13–13. Halide torch.

employ acetylene gas or alcohol as a fuel. The acetylene burning torch has been found to be the most satisfactory type for locating Freon–12 leaks. If a pump pressure type of alcohol-burning torch is used, care must be taken that the air pumped into the tank is pure.

To obtain most satisfactory results in using the halide leak detector, the following precautions must be observed:

1. Be sure that the reactor plate is in place.

2. Adjust the flame low enough so that it does not extend appreciably beyond the end of the burner. A small flame is much more sensitive than a large flame.

If it is difficult to adjust the torch to the desired setting, block the end of the exploring hose until the flame ignites, then open the hose gradually. (DON'T use the torch if the surrounding atmosphere is known to be heavily contaminated with Freon–12.)

3. If the flame persists in burning with a white or yellow color, the exploring tube is partially blocked with dirt and should be cleaned.

4. Check to see that air is being drawn into the exploring tube by holding the end of the tube to the ear from time to time.

5. Hold the exploring tube close to the joint being tested, to prevent dilution of the sample by stray air currents.

6. Move the end of the exploring hose slowly and completely around each joint. Leak testing cannot safely be hurried. There is a definite time lag between the moment when air enters the exploring hose and the moment when it reaches the reactor plate.

7. If a greenish flame is noted at any time, repeat the test in the same vicinity until the source of the Freon–12 is determined. If necessary, use soap bubbles to find the exact point at which a leak is occurring.

8. After a system has been operated, the lubricating oil circulates with the refrigerant in the system; where a leak exists the oil usually collects on the exterior of the piping joints, etc., indicating the approximate location of system leaks. This oil must be carefully removed before the halide detector is used to determine the exact location of the leakage.

9. Always follow a definite procedure in testing for leaks, so that no joints will be missed. Be sure that you locate every leak; even a very small leak is not to be considered negligible. The extra time spent in testing all threaded, flared, soldered, welded, and valve cap gasket joints will be justified.

10. The system must never be recharged until all leaks are discovered and definitely repaired. When one leak has been discovered, *retest the system for other possible leaks.*

SOAPSUDS. A halide torch is so sensitive that it is useless if the atmosphere is contaminated by successive leakage of Freon–12. This is most likely to happen in a small or poorly ventilated compartment. In such a case, the soapsuds test must be used.

Prepare the soap-and-water solution so that it has the consistency of liquid hand soap, and will work up a lather on a brush. The lather will remain wet for a longer period if a few drops of glycerin are added to the solution.

Apply the lather on the entire joint, and then look carefully for bubbles. If a joint is so located that a part of it is not visible, use a small mirror to inspect it. Remember that it sometimes takes as long as a minute or more for bubbles to appear at a small leak. Doubtful spots should be lathered and examined a second time.

Repair of Leaks

If a leak has been detected in a system equipped with a liquid receiver, proceed as follows:

1. Close the liquid receiver valve, see that the compressor discharge valve is in the OPEN position.
2. Start the motor and operate until a vacuum of 28 inches is obtained.
3. Stop the motor and close the compressor valves.
4. Admit a sufficient amount of Freon into the low side of the system until zero is indicated on the compound gage. (To accomplish this, crack the liquid receiver valve by opening approximately ½ turn, and watch the gage pressure rise.)
5. Make the necessary repairs.
6. After any repairs have been made whereby it was necessary to pump the charge back to the liquid receiver, air which entered the system must be removed before

readmitting the refrigerant. In such cases proceed as follows:

a. Remove the plug from the gage opening of the compressor discharge valve.

b. Place a dry rag over the plug opening, start the motor and begin to draw a vacuum on the system. When a vacuum of 20 inches is obtained, run the motor intermittently until a vacuum of 28 inches is reached. This procedure will usually prevent the compressor from pumping oil.

c. If the compressor is pumping oil, stop the motor and turn the compressor over slowly, by hand.

d. Screw a pressure gage into the opening of the discharge valve.

e. Open the liquid receiver valve slightly until the vacuum is displaced with a pressure of 3 psi, then turn in (close) the valve. Test all joints and other possible areas for leaks. If no leaks appear at this pressure, open the liquid receiver valve until 15 or 20 psi is reached, then test the doubtful areas again for leaks.

If a leak has been detected in a system not equipped with a liquid receiver, it can generally be stopped by tightening the affected joint(s). If the leak cannot be stopped and the system has no receiver, the refrigerant should be removed from the system to a clean, dry, empty cylinder as follows:

1. Open (turn out) the compressor discharge valve. Remove the pressure gage and connect the opening in the valve to a clean, dry cylinder with a 1/4-inch tubing.

2. Purge the air from this line at the connection to the cylinder by leaving the flare nut loose at the cylinder end and cracking the discharge valve, then closing it again quickly.

3. Tighten the flare nut.

4. Place the cylinder on end in a pail of water (cold or ice), the valve end uppermost with the valve and part of the cylinder above the water level.

5. Close the compressor discharge valve, all the way to the right, and open the valve on the cylinder.

6. Start the compressor motor and operate it until enough refrigerant has been drawn out of the system into the drum so that the internal pressure will remain two or three psi above zero gage, or atmospheric pressure. (The reason for this is to have a slight excess pressure above atmospheric so that when a fitting is loosened a small amount of gas will come out instead of air entering the system.)

7. Open the compressor discharge valve when the pressure is equalized (2 to 3 psi) at both sides, and close the cylinder valve.

Pumping Down the System

Whenever it is necessary for you to open a charged or operating refrigerating system in order to make repairs or replacements, or to clean strainers, the Freon pressure within the part of the system to be opened must be pumped down ($\frac{1}{2}$ to 5 psi above atmospheric pressure), before you break any of the connections.

For repairs that can be made to segregated parts of the system, without securing the entire plant, the liquid and vapor refrigerant should be pumped out by closing the shut-off valves in the feed line. As part of the system containing liquid Freon is pumped down, its normally warm temperature decreases, due to evaporation of the liquid. When the temperature of the part being pumped down begins to rise to normal again, it is reasonably certain, if the low pressure has been maintained in the part, that all the contained Freon liquid has been evaporated.

It is generally possible to pump down nearly every part of the refrigerating system by the proper manipulation of cutout valves. However, this is not so for the

condenser, receiver, and compressor discharge line. For these units, the liquid Freon must be drained into a service drum. This draining procedure is explained under "Charging the System." (see page 552).

If a pressure below 0 psi is accidentally reached during the pumping-down procedure, sufficient refrigerant must be immediately bled into the evacuated part of the system to raise the pressure to between ½ to 2 psi. The connections may then be opened, and repairs, or other necessary service operation performed. In order to prevent the entrance of air and dirt, the free ends of the refrigerant lines should be temporarily plugged.

When connections are remade, one connection should be made tight, and the other(s) left loose until air or other foreign gases in the serviced section of the system can be swept out through the free end, by slowly purging it with Freon gas bled from the charge in the system. The other connection, or connections, should be tightened immediately.

When connecting lines are removed, the ends of these lines should be capped to protect the fittings and to ensure clean tubes when used again.

Cleaning of Strainers

The suction scale trap and liquid strainers should be cleaned after the first few hours of operation to remove the foreign matter loosened from the system by the solvent action of the Freon–12, and circulated through the lines to these units. Another cleaning is usually necessary after the first few days of operation.

The strainers should be inspected frequently during the early service life of the plant and after major repairs. A schedule should be set up as soon as possible to provide for cleaning strainers at regular intervals.

SUCTION STRAINERS.—The strainer in the Freon vapor suction line at the compressor, serving to prevent scale or foreign matter from entering the compressor, must be cleaned occasionally. To do this, first pump down the com-

pressor. Before opening the strainer, be sure that an accurate gage shows slightly above atmospheric pressure. Remove the body cover of the strainer, take out the strainer, and immediately replace the cover to prevent air and foreign matter from entering the system. Wash the strainer and spring in an approved solvent, then dry them in the air. Clean the strainer seat inside the body, taking care to wipe out particles falling into the body. Use only chamois or lint-free cloth. If this strainer seat is not clean, dirt may pass into the compressor because of faulty seating of the screen. In reassembling, see that the cover gasket is in good condition and that the body capscrews are drawn up evenly.

LIQUID STRAINERS. The procedure used for cleaning liquid strainers is generally similar to that outlined for cleaning the suction scale trap, except that the pumping out process should be accomplished as outlined in the preceding section of this training course.

Charging the System

A refrigerating system should have an adequate charge of refrigerant at all times; otherwise its efficiency and capacity will be impaired. The amount of Freon–12 charge must be sufficient to maintain a liquid seal between the condensing and evaporating sides. When the low-pressure switch stops the compressor, the liquid receiver of a properly charged system is generally about 85 percent full of Freon–12. The Freon–12 charge necessary for an individual plant is usually stated in the plant instruction book or on the ship's drawings.

The dehydrator, located in the liquid line between the receiver and the evaporator, should be put into service when charging or adding Freon–12 to the system, or when the presence of moisture in the system is suspected.

To charge additional Freon–12 into a refrigerating system, first check the entire system for leaks, and then proceed as follows:

1. Weigh the service cylinders to be used to charge the system, and determine the weight of Freon–12 contained in them by comparing the total weight with the weight stamped on each cylinder. It is important to know how much Freon is added to the system. The amount of refrigerant charged may be determined by mounting the charging drum on a scale and noting the loss of weight as charging progresses.

2. Connect one of the service drums to the system charging connection.

3. Open the cylinder valve slightly, and blow out the air in the charging line.

4. Close the cylinder valve and tighten the connection.

5. Open the cylinder valve slightly, and test the charging line and its connections for leaks.

6. Close the liquid line valves in the discharge lines from the receiver, as well as the liquid line valve between the dehydrator connections to the main liquid line.

7. See that the valves in the dehydrator line are open.

8. Open the valve on the service cylinder and the system charging valve, and gradually admit sufficient refrigerant to the system until the pressure in the service cylinder is equal to the system pressure. (These pressures will equalize at a Freon–12 pressure corresponding approximately to the temperature of the liquid Freon in the service cylinder.)

9. Close the bypass valves around the liquid control valve assemblies and around the suction pressure regulating valves, if installed.

10. See that the coils of the solenoid valve are energized and that the automatic control equipment is working properly.

11. If the system is equipped with a cross-connecting line between the condenser inlet connections, close the stop valves in this line.

12. Start one of the compressors on AUTOMATIC control, and observe all starting precautions. (Avoid rapid

pumping down of the crankcase pressure; rapid reduction in crankcase pressure will cause violent boiling and foaming of the lubricating oil as the Freon–12 absorbed by the oil is released.)

13. If the system is equipped with water-cooled condensers, see that there is sufficient circulating water to maintain the condensing pressure at 125 psi gage. In addition, see that the condenser water chests are properly vented.

14. If the system charging connection is located in the compressor suction line, gradually open the liquid valve at the discharge of the receiver of the compressor unit. Then open the valves in the charging line and operate the compressor until the required amount of refrigerant has been charged into the system. (If additional service drums are required, the compressor should be stopped while an empty drum is disconnected and a new one connected to the system. Before a drum is disconnected, the charging line should always be pumped down.)

To REMOVE FREON from the system, connect a cold, empty drum to the liquid charging valve. Open the valve, and drain the system until the drum pressure equals the system pressure.

Checking for Noncondensable Gases

Noncondensable gases or air in a condenser cause excessive condensing pressures, with resulting inefficiency, and should never be allowed to remain in the system. When a check is being made for noncondensable gases, the system should have sufficient refrigerant so that the liquid refrigerant present in the receiver will seal the liquid line connection. The best time to check the Freon–12 system for the presence of noncondensable gases is immediately before the compressor starts, after a temporary or prolonged shutdown period.

To check for noncondensable gases, proceed as follows:

1. Close the liquid line valve.

2. Secure the compressor and close the suction line valve.

3. Determine the actual condensing temperature. When no further decrease is noticed in the discharge pressure, the approximate actual condensing temperature has been reached.

4. Read the condensing temperature which corresponds to the condensing pressure registered by the high-pressure gage. This will be the condensing temperature of pure Freon–12 at this pressure.

5. Subtract the existing condensing temperature (step No. 3) from that of pure Freon–12 at the existing condenser pressure (step No. 4). If the difference between these two temperatures is more than 5° F, it will be necessary to purge the system.

In order to perform the above test, it may be necessary to install a service gage in the compressor discharge connection. If a thermometer is not installed in an air-cooled condenser application, one should be placed near the condenser to record the ambient temperature at that location.

Purging Noncondensable Gases

If noncondensable gases are present in the condenser, slowly release the gases by using the purge valve, or, if no purge valve is provided, by opening the discharge gage connection.

The proportion of Freon–12 gas, mixed with the noncondensable gases, that will escape while the condenser is being purged depends upon the rate of purging and the concentration of the noncondensable gases. To date, there is no practical test available aboard ship to determine when an excess proportion of Freon–12 gas is being purged, and when the purging operation should be discontinued. However, to maintain the Freon–12 loss to a minimum, purge slowly and continually check the

condenser for noncondensable gases, as explained in the previous section.

Freon–12 resembles carbon tetrachloride in odor. However, it is odorless in concentrations of less than 20 percent by volume in air. If the operator can get close to the purge valve discharge, it is possible to determine when purging should be discontinued and the check for noncondensable gases repeated. (During this operation, goggles should be worn. In addition, since Freon-12 is very expensive, unnecessary waste or refrigerant should be avoided.)

Purging Air After Repair

After a system has been open for repair, it is advisable to check for air in the system before proceeding with regular operation. This check may be made by either of two methods; the preferred method is as follows:

1. Close the liquid king valve from the receiver.
2. Pump down the system to 5 inches of vacuum. (While pumping down, open wide the circulating water valves, in order to condense all condensable vapors, and operate with the lowest possible head pressure.)
3. Shut down the compressor.
4. Close the discharge valve on the compressor.
5. Close the stop valve from the condenser to the receiver.
6. Attach a small hose to the air-purge valve on the condenser.
7. Insert the other end of the hose in a glass jar or vessel filled with water or light machine oil.
8. Crack the purge valve on the condenser. If there is air in the system, large bubbles will appear in the water. When all the air is out, small bubbles of Freon will appear in the water and a sharp, cracking sound will be heard. Then the purge valve should be closed and the system put into normal operation.

The other method of testing for air in the system, by observing temperature, is as follows:

1. Operate the system for 30 minutes. Observe the pressure and temperature as indicated on the high-pressure Freon gage.

2. Read the thermometer in the liquid line, and compare it with the temperature conversion figures shown on the discharge pressure gage. If the temperature of the liquid leaving the receiver is more than 15° F lower than the temperature corresponding to the discharge pressure, the system should be purged.

3. Open the purge valve slightly, while the system is still operating. Purge very slowly, at intervals, until the air is expelled from the system and the temperature difference drops below 15° F.

Cleaning of Condenser Tubes

If the difference between the temperature of the outlet circulating water and the temperature corresponding to the condensing pressure increases 5° to 10° F above the temperature difference obtained when the condenser was in good condition and operating under similar heat loads, and if this difference is not caused by an overcharge of refrigerant or noncondensable gases, the condenser tubes are dirty, and must be cleaned.

In order to clean the condenser tubes properly, it is necessary first to drain the cooling water from the condenser and then to remove the water connections and water chests. When the water chests are removed, be careful not to damage the gaskets between the tube sheet and the water side of the water chest. Tubes should be inspected as often as practicable and be cleaned as necessary by the use of an approved method for cleaning steam condenser tubes, as recommended in chapter 46 of BuShips *Manual*. Rubber plugs and an air or water lance should be employed when necessary to remove foreign deposits. It is essential that the tube surfaces be kept clear of particles of foreign matter; however, care

must be taken not to destroy the thin protective coating of corrosion products on the inner surfaces of the tubes. If the tubes become badly corroded, they should be replaced in order to avoid the possibility of losing the Freon–12 charge and admitting salt water to the Freon–12 system.

Cleaning Air-Cooled Condensers

Although the large Freon–12 plants are equipped with water-cooled condensers, auxiliary units are commonly provided with air-cooled condensers, and this eliminates the necessity for circulating water pumps and piping.

The exterior surface of the tubes and fins on an air-cooled condenser should be kept free of dirt or any matter that might obstruct heat flow and air circulation. The finned surface should be brushed clean with a stiff bristle brush as often as necessary. When installations are exposed to salt spray and rain through open doors or hatches, care should be taken to minimize corrosion of the exterior surfaces. The finned surface is usually coated with solder and should never be painted; it may be retinned if necessary.

Testing Condensers for Leaks

To prevent serious loss of refrigerant through leaky condenser tubes, the condenser should be tested for leakage once every two weeks. The test should always be conducted on a condenser that has not been in use for at least 12 hours. Slowly open the valves on the water side, one at a time, and insert the exploring tube of a leak detector. If this test indicates that Freon–12 gas is present, the exact location of the leak may be detected as follows:

1. Remove the water heads and listen at each section for the hissing sound that indicates gas leakage. If the leak cannot be definitely located, all the tubes must be checked. However, if the probable location of the leaky tubes is found, treat that section as follows:

2. Wash the tube heads, and with a cloth or ball of cotton clean all tubes (while wet) until the inner walls are dry and shining. Then hold the exploring tube in one end of each condenser tube for about 10 seconds. As soon as fresh air is drawn into the tube, drive a cork into each end of the tube. If necessary, repeat this procedure with all the tubes in the condenser. Before proceeding further, allow the condenser to remain in this condition for 48 hours.

3. After the tubes have been corked up for 48 hours, put 3 men on the job, one to remove corks at one end, another to remove tubes at the other end and handle the exploring tube, and the third man to watch the color of the flame in the lamp. Start with the top row of tubes in the section being inspected, remove the corks simultaneously at each end of the tube, and insert the exploring tube for 5 seconds.

4. Mark any leaky tubes for later identification.

5. Leakage of any of the tube joints is indicated by the presence of oil at the joint, after the 48-hour period.

To date this procedure has been found to be the only method which gives conclusive evidence; in most cases, this method has given satisfactory results.

Checking Compressor Oil

If the apparent oil level observed immediately after a prolonged shut-down period is lower than normal, it is almost certain that the actual working oil level is far too low. After a sufficient quantity of oil has been added to raise the apparent oil level to the center of the bull's eye sight glass, the actual oil level should be checked as follows:

1. Operate the compressor on MANUAL control for at least one hour. Then slowly close the suction line stop valve. If the compressor is operating on a water cooler or other coil which is apt to freeze, observe the temperature and interrupt compressor operation as necessary to

prevent freezing. Repeat cycling until the total running time (one hour) is obtained.

2. Stop the compressor, turn the flywheel until the crankshaft and connecting rod ends are immersed in the lubricating oil, and immediately observe the oil level in the sight glass.

To check the oil level when the compressor has been running on its normal cycle, with no abnormal shutdown period, proceed as follows:

1. Wait until the end of a period of operation; if the operation is continuous, wait until the compressor has been in operation at least $\frac{1}{2}$ hour.

2. As soon as the compressor stops, turn the flywheel until the crankshaft and connecting rod ends are satisfactorily immersed in the lubricating oil, and observe the oil level in the sight glass.

Do not remove oil from the crankcase because of an apparent high level unless too much oil has been previously added, or unless it is apparent that oil from the crankcase of one compressor of the plant has been inadvertently deposited in the crankcase of another.

However, if the oil level is lower than its recommended height on the glass, a sufficient quantity of oil should be added to obtain the desired level. Do not add more oil than is necessary; too much oil can result in excessive oil transfer to the cooling coils.

ADDING OIL.—There are two common methods of adding oil to a compressor. In one type of installation, a small oil-charging pump is furnished for adding oil to the compressor crankcase. In another type, oil is placed in the compressor by means of a clean, well-dried funnel. In either case, care must be taken to prevent the entrance of air or foreign matter into the compressor.

When performing hourly checks of the compressors, you may observe no oil in the crankcase, or a very low oil level on the sight glass. This indicates that the oil has left the compressor and is circulating in the system. In

this case, it will be necessary to add oil and operate the system. After the compressor has reclaimed the excessive oil in the system, the excess oil should be drained.

REMOVING OIL.—To remove oil from the compressor crankcase, reduce the pressure in the crankcase to approximately 1 psi by gradually closing the suction line stop valve. Then stop the compressor, and close the suction and discharge line valves, loosen the lubricating oil drain plug near the bottom of the compressor crankcase, and allow the required amount of oil to drain out. Since the compressor crankcase is under a slight pressure, do not fully remove the drain plug from the compressor, but allow the oil to seep out around the threads of the loosened plug. When the desired amount of oil has been removed, tighten the drain plug, open the suction and discharge line valves, and start the compressor. If an oil drain valve is provided in lieu of a plug, the required amount of oil may be drained without pumping down the compressor.

RENEWING THE LUBRICATING OIL CHARGE.—When clean copper tubing is used for Freon–12 mains and evaporators, and reasonable care has been taken to prevent the entrance of foreign matter during installation, the oil in the compressor crankcase will probably not become so contaminated that it requires renewal more than once a year. When iron or steel pipe and fittings are used in the Freon–12 system, a sample of oil from the compressor crankcase should be withdrawn into a clean glass vessel every three months. If the sample shows contamination, the entire lubricating oil charge should be renewed. It is good practice to check the cleanliness of the lubricating oil after each cleaning of the compressor suction scale trap.

Care of V-Belts

Excessive looseness will cause slippage, rapid wear, and deterioration of V-belts. On the other hand, a belt that is too tight will cause excessive wear of both the belt and the main bearing of the compressor. In extreme cases it

may cause a bad seal leak. When properly tightened, a belt can be depressed ½ to ¾ inch, by the pressure of one finger, at a point midway between the flywheel and the motor pulleys.

When replacement of one belt of a multiple V-belt drive is necessary, a complete new set of matched belts should be installed. Belts stretch considerably during the first few hours of operation. Replacement of a single belt will upset the load balance between the new and old belts and will be a potential source of trouble. It is better practice to run the unit temporarily with a defective belt removed than to attempt to operate a new belt in conjunction with two or more seasoned belts.

V-belts, motor pulleys, and compressor flywheels should be kept dry and free of oil. Belt dressing should never be used.

Testing and Renewing Compressor Discharge and Suction Valves

A Freon–12 compressor should NOT BE OPENED for valve inspection or replacement until it has been determined that the faulty operation of the system is caused by improper functioning of the valves. Faulty compressor valves may be indicated by a gradual or by a sudden decrease in the normal compressor capacity. Either the compressor will fail to pump at all, or else the suction pressure cannot be pumped down to the designed valve, and the compressor will run for abnormally long intervals (or even continuously). If the compressor shuts down for short periods, the compressor valves may be leaking.

If the refrigeration plant is not operating satisfactorily, it will be best to first shift the compressor and then check the operation of the plant. If the operation of the plant is satisfactory when the compressors have been shifted, this indicates that the trouble was with the compressor. However, if faulty operation of the plant is still indicated after the compressors have been shifted, the trouble is in the system, and not in the compressor.

The compressor discharge valves may be tested by

pumping down the compressor to 2 psi gage, then stopping the compressor, and quickly closing the suction and discharge line valves. If the discharge pressure drops at a rate in excess of 3 psi per minute and the crankcase suction pressure rises, there is evidence of compressor discharge valve leakage. If it is necessary to remove the discharge valves with the compressor pumped down, break the connection to the discharge pressure gage in order to release discharge pressure on the head.Then remove the compressor top head and discharge valve plate, being careful not to damage the gaskets.

If the discharge valves are defective, the entire discharge valve assembly should be replaced. Any attempt to repair the valve would probably involve relapping, and would require highly specialized equipment. Except in an emergency, such repair should never be undertaken aboard ship.

The compressor internal suction valves may be checked for leakage by performing the steps which follow.

1. Start the compressor by using the manual control switch on the motor controller.

2. Close the suction line stop valve gradually, to prevent violent foaming of the compressor crankcase lubricating oil charge.

3. Pump a vacuum of approximately 20 inches Hg. If this vacuum can be readily obtained, the compressor suction valves are satisfactory.

Do not expect the vacuum to be maintained after the compressor stops because Freon–12 being released from the crankcase oil will cause the pressure to rise. Do not attempt to check compressor suction valve efficiency of new Freon–12 units until after the compressor has been in operation for at least three days. It may be necessary for the valves to wear in.

However, if any of the compressor valves are defective, the compressor should be pumped down, opened, and the valves inspected. Defective valve(s) or pistons should be replaced with spare assemblies.

Repair of Compressors

If the compressor is damaged to such an extent that it cannot be operated, it will be necessary, before opening the unit for repairs, to close the suction and discharge stop valves and permit the refrigerant in the compressor to escape to the atmosphere through gage lines or purge valves.

Before opening and operating compressor for examination or repair, it is necessary to pump down the system. To pump Freon–12 out of the compressor, proceed as follows:

1. Close the suction stop valve.
2. See that the compressor discharge valve is open.
3. Start the compressor and let it run on manual control until a slight vacuum is obtained.
4. Stop the compressor and immediately close the discharge stop valve. If the pressure indicated by the suction gage rises rapidly to 15 psi, or more, above zero pressure, there is still a considerable amount of Freon–12 in the crankcase. In this case, start the compressor with the manual control switch, and gradually close the suction valve. When the valve is completely closed, let the compressor run until the maximum vacuum is obtained.
5. After the vacuum is pumped, wait until the pressure builds up to 2 or 3 psi before opening any part of the compressor or its connections.
6. Before proceeding with any work on the compressor, see that the switch is open, and fuses removed.

DISASSEMBLY.—Before dismantling a compressor, make certain that the faulty operation of the installation is not caused by trouble in some other part of the system. Dismantle only the part of the compressor necessary to correct the fault.

Never open any part of the compressor unless the gage indicates a positive pressure inside the system.

As soon as internal machined parts (valves, pistons, shaft seal, crankcase) are removed, wrap them in clean paper to protect them from corrosion or other damage.

When disassembling the compressor, be careful not to injure the gaskets. When reassembling, use gaskets of identical thickness and material—the thickness determines the clearance between the top of the compressor pistons and the discharge valve plate.

To disassemble or reassemble the compressor, use only the tools specified for the particular operation involved.

REASSEMBLY.—Before a compressor is reassembled, all parts—including replacement parts—should be carefully washed with an approved cleaning agent, or solvent and permitted to dry in air. The final rinse should be made with a clean solution. Using chamois or hard, lint-free cloth facilitates cleaning. Care should be taken to prevent dirt, lint, water, or other foreign matter from entering the compressor during reassembly.

REPLACEMENT OF PARTS.—Where necessary to remove, replace, or repair internal parts of the compressor, the manufacturer's instruction book should be consulted. The following precautions should be observed:

1. Carefully disassemble and remove parts, noting the correct relative position so that errors will not be made upon reassembly.

2. Inspect all parts that have been made accessible by removal of the parts requiring repair or replacement.

3. See that all parts, as well as surfaces, are free of dirt and moisture.

4. Apply compressor oil freely to all bearing and rubbing surfaces of parts being reinstalled.

5. If the compressor is splash-lubricated, see that the oil dipper on the lower connecting rod bearing is in correct position for dipping up oil when the machine operates.

6. Position the ends of the piston rings so that alternate joints do not come on one side of the piston.

7. Remove the oil; clean the gasket surfaces and replace old gaskets with new ones.

8. Clean the crankcase and provide a fresh charge of oil.

SAFETY PRECAUTIONS

When working with Freon–12 refrigeration systems, observe the following safety precautions:

1. Inspect the oil level in the compressor before starting.
2. Inspect the oil pressure in the forced-feed compressor systems.
3. Don't admit any air into the system.
4. Don't allow dirt to enter the system.
5. Prevent mechanical injury and depreciation.
6. Check the system regularly.
7. Test the system for leaks.
8. Don't allow the crankcase to become cold or frosted.
9. Don't permit the suction scale trap to become frosted.
10. Drain water from idle condensers.
11. Wear goggles in order to prevent liquid Freon from getting in your eyes when you charge or purge the system.

If liquid Freon–12 accidentally comes in contact with the eyes, introduce drops of sterile mineral oil (or olive oil) as an irrigant. Take every precaution to see that the victim does not rub his eyes. If possible, the person suffering an injury of this nature should be taken immediately to the medical officer.

If liquid Freon–12 comes in contact with the skin, treat the area the same as though the skin had been frostbitten or frozen.

A person overcome in a space which lacks oxygen because of high concentrations of Freon–12 should be removed to a space where fresh air is available before giving artificial respiration.

SUMMARY

The EN2 should be familiar with Freon–12 refrigerating plants installed aboard naval vessels. He should know the locations and the functions of the component parts of the system.

As an EN2, you must know how to pump down refrigerant systems as well as check for noncondensable gases; and how to detect leaks throughout the system.

Your knowledge of the Freon–12 compressor units and the lubrication system should comprise the following: how to check the lubricating oil level, how to add lubricating oil as well as remove it from the compressor crankcase, and how to test and renew compressor valves.

QUIZ

1. What type of compressor suction and discharge valves are generally employed with refrigeration systems?
2. Freon–12 compressors may be provided with what types of lubrication?
3. How is leakage of the refrigerant and lubricating oil from the compressor crankcase prevented?
4. What unit acts as a seal between the vapor in the condenser and the flow of liquid to the expansion valve?
5. What methods are used to join the various sections of copper tubing, piping, and fittings of the refrigeration system?
6. What types of stop valves are used by the Navy?
7. What unit operates to stop the flow of liquid refrigerant to the evaporator when the space being cooled has reached the desired temperature?
8. What functions to stop the flow of refrigerant from the receiver when the compressor stops for any reason other than suction pressure control?
9. To minimize the possibility of Freon–12 leakage by eliminating a considerable amount of piping, as well as fitted joints, what is installed in a refrigeration system?
10. When does the low-pressure cutout switch stop the compressor?
11. In the event of failure of the circulating water supply, what unit automatically stops the compressor?
12. It is advisable to defrost the cooling coils before the average frost reaches what thickness?
13. What is provided on many Freon–12 plant installations to facilitate defrosting?
14. A shortage of refrigerant necessitates what action?
15. What device is generally employed to test the refrigeration systems for leaks?

16. Whenever it is necessary to open a charged system, what step must be taken immediately?
17. What must be done if, in pumping down a Freon–12 refrigerating system, a pressure below 0 psi is accidentally reached?
18. When should the dehydrator be used in a Freon–12 refrigeration system?
19. When is it best to check the system for the presence of noncondensable gases?
20. If a system has been open for repair, what should be done immediately before proceeding with regular operation?
21. When should a Freon–12 system be purged of air?
22. When can an over-all check for water-cooled condenser performance be used to indicate the condition of the condenser surface?
23. What may result if badly corroded condenser tubes are not replaced?
24. How often should condensers be tested for leakage?
25. When removing oil from the compressor, why should the drain plug NOT be completely removed?
26. When is it best to check the cleanliness of the lubricating oil?
27. What type of belt dressing should be used on compressor V-belts?
28. What indicates a faulty compressor valve?
29. How may compressor discharge valves be tested?
30. If the discharge valves are defective, what procedure should be taken?
31. When should the efficiency of new compressor suction valves be checked?
32. What source of information should be consulted when it is necessary to remove, replace, or repair internal parts of the compressor?

CHAPTER 14

VENTILATION AND AIR CONDITIONING

Air conditioning is a field of engineering dealing with the design, construction, and operation of equipment used in establishing and maintaining desirable indoor air conditions. It is the science of maintaining the atmosphere of an enclosure at any required temperature, humidity, and purity. As such, air conditioning involves the cooling, heating, dehumidifying, ventilating, and purifying of air.

One of the chief purposes of air conditioning is to keep the ship's crew comfortable, alert, and physically fit. The air of various compartments must be of the right temperature, have the proper moisture content, be free of contamination, be circulated properly, and have the correct proportion of oxygen. It must be remembered that the human body cannot long maintain a high level of efficiency under adverse conditions.

However, the comfort and fitness of the crew is not the only immediate purpose of air conditioning. Mechanical cooling or ventilation must also be provided for AMMUNITION SPACES to prevent deterioration of ammunition components; for GAS STORAGE SPACES, to prevent excessive expansion or contamination; and for ELECTRICAL EQUIPMENT SPACES, to limit ambient (encompassing) temperature to that specified for the equipment.

This chapter covers the principal factors involved in the conditioning of air, the type of equipment used in ventil-

ating, cooling, and heating the air, and general information concerning the maintenance of air conditioning equipment. Additional information may be obtained from chapter 38 of BuShips *Manual.*

HUMIDITY AND HUMAN COMFORT

Vapor content of the atmosphere, called HUMIDITY, has a great influence on human comfort. The common expression, "It isn't the heat, it's the humidity," is an indication of the popular recognition of the discomfort—producing effects of moisture—laden air in hot weather. Extremely low moisture content also has undesirable effects on the human body. The measurement and control of the moisture content of the air is an important phase of air conditioning engineering. In order to understand this phase of air conditioning engineering, you should become familiar with the information given in the following paragraphs.

Saturated Air

The air holds varying amounts of water vapor, and, as temperature rises, the amount of moisture that the air can hold increases. But for every temperature there is a definite limit as to the amount of moisture that the air is capable of holding. When air attains the maximum amount of moisture which it can hold at a specific temperature, it is said to be saturated.

Dew Point

The saturation point is usually called the dew point. If the temperature of saturated air falls below its dew point, some of the water vapor in the air must condense to water. The dew that appears on foliage in the early morning when there is a drop in temperature is such a condensation. The "sweating" of cold water pipes is the result of water vapor from the air condensing on the cold surface of the pipes.

Absolute and Specific Humidity

The amount of water vapor in the air is expressed in terms of the weight of the moisture. This weight is usually given in grains (7000 grains equal 1 pound). Absolute humidity is the weight in grains of water vapor per cubic foot of air. Specific humidity is the weight in grains of water vapor per pound of air. (The weight of water vapor refers only to moisture in the vapor state, and not in any way to the moisture that may be present in the liquid state, such as rain, or dew.)

Relative Humidity

Relative humidity is the ratio of the weight of water vapor in a sample of air to the weight of water vapor that same sample of air would contain if saturated, at the existing temperature. This ratio is usually stated as a percentage. For example, when air is fully saturated, its relative humidity is 100 percent. When air contains no moisture at all, its relative humidity is zero percent. If air is half saturated, its relative humidity is 50 percent.

As far as comfort and discomfort resulting from humidity are concerned it is the relative humidity and not the absolute or specific humidity that is the important factor. This can be easily understood from the discussion that follows.

Moisture always travels from regions of greater wetness to regions of lesser wetness, just as heat travels from regions of higher temperature to regions of lower temperature. If the air above a liquid is saturated, the two are in equilibrium and no moisture can travel from the liquid to the air; that is, the liquid cannot evaporate. If the air is only partially saturated, some moisture can travel to the air; that is, some evaporation can take place.

If the specific humidity of the air is 120 grains per pound, it is the actual weight of the water vapor in the air. When the temperature of the air is 76° F, the relative humidity is then nearly 90 percent—that is, the air is nearly saturated. At such a relative humidity, the

body may perspire freely but the perspiration does not evaporate rapidly; thus a general feeling of discomfort results.

However, if the temperature for the air were 86° F, the relative humidity would then be only 64 percent. That is, although the absolute amount of moisture in the air is the same, the relative humidity is lower, because at 86° F the air is capable of holding more water vapor than it can hold at 76° F. The body is now able to evaporate its excess moisture and the general feeling is much more agreeable, even though the temperature of the air is 10° higher. (The cooling effect is brought about by the absorption of latent heat during the evaporating process.)

In both cases, the specific humidity is the same, but the ability of the air to evaporate liquid moisture is quite different at the two temperatures. This ability to evaporate moisture is directly indicated by the relative humidity. It is for this reason that the control of relative humidity is of extreme importance in air conditioning.

HEAT OF THE AIR

The heat of the air is considered from three standpoints—differentiated as sensible, latent, and total heat.

SENSIBLE HEAT is the heat that changes the temperature of a substance (air) when added to or abstracted from it. Sensible heat changes can be measured by the household, or dry-bulb thermometer.

Air nearly always contains more or less water vapor. Conditions of complete absence of moisture are rare, occurring perhaps only in desert regions. Any water vapor in the air contains the LATENT HEAT OF VAPORIZATION. (Remember that the amount of latent heat present has no effect upon the temperature of the air, as read on a dry-bulb thermometer.)

Any mixture of dry air and water vapor—that is, air as we usually find it—contains both sensible and latent heat. The sum of the sensible heat and the latent heat in any sample of air is called the TOTAL HEAT of the air.

AIR CONDITIONING TEMPERATURES

When testing the effectiveness of air conditioning equipment and when checking the humidity of a space, three different temperatures are generally considered. These are the dry-bulb, wet-bulb, and dew point temperatures.

Measurement of Temperatures

The DRY-BULB TEMPERATURE is the temperature of the sensible heat of the air, as measured by an ordinary thermometer. Such a thermometer in air conditioning engineering is referred to as a dry-bulb thermometer because its bulb is dry, in contrast with the wet-bulb type next described.

The WET-BULB TEMPERATURE is best explained by a description of a wet-bulb thermometer. It is an ordinary thermometer, with a loosely woven cloth sleeve or wick placed around its bulb and then wet with water. The water in the sleeve or wick is caused to evaporate by a current of air at high velocity. This evaporation withdraws heat from the thermometer bulb, lowering the temperature a number of degrees. The difference between the dry-bulb and the wet-bulb temperatures is called the wet-bulb depression. The wet-bulb temperature is the same as the dry-bulb when the air is saturated (that is, when evaporation cannot take place). The condition of saturation, however, is unusual, and a wet-bulb depression is normally expected.

The wet-bulb and dry-bulb thermometers are usually mounted side by side on a frame, to which a handle or short chain is attached so that the thermometers may be whirled in the air, thus providing a high-velocity air current that promotes evaporation. Such a device is known as a SLING PSYCHROMETER. When using the sling psychrometer, whirl it rapidly, at least four times per second. Observe the wet-bulb temperature at intervals. The point at which there is no further drop in temperature is the wet-bulb temperature for that space.

The temperature at which DEW POINT occurs depends upon the amount of water vapor in the air. If the air at a certain temperature is not saturated, and the temperature is lowered, a point is finally reached at which the air is saturated for a lower temperature and condensation of moisture then begins. This temperature is the dew point of the air for the quantity of water vapor present.

Relationships between the Temperatures

The definite relationships between the three temperatures should be clearly understood. These relationships are:

1. When the air contains some moisture but is not saturated, the dew-point temperature is lower than the dry-bulb temperature, and the wet-bulb temperature lies between them.
2. As the amount of moisture in the air increases, the differences between the temperatures become less.
3. When the air is saturated, all three temperatures are the same.

PSYCHROMETRIC CHART

There is a relationship between dry-bulb temperature, wet-bulb temperature, dew-point temperature, specific humidity, and relative humidity. Given any two, the others can be calculated. The relationship can be shown on a psychrometric chart (fig. 14–1). In air conditioning, it is customary to use this chart, since reading measurements from the chart is far easier than calculating these measurements from two given factors.

Note that in this chart the wet-bulb and dew-point temperature scales lie along the same line, which is the 100-percent relative humidity line. However, the dew-point temperature lines run horizontally, and the wet-bulb temperature lines run obliquely down to the right. To use the chart, take the point of intersection of the lines of the two known factors, and from this point follow the

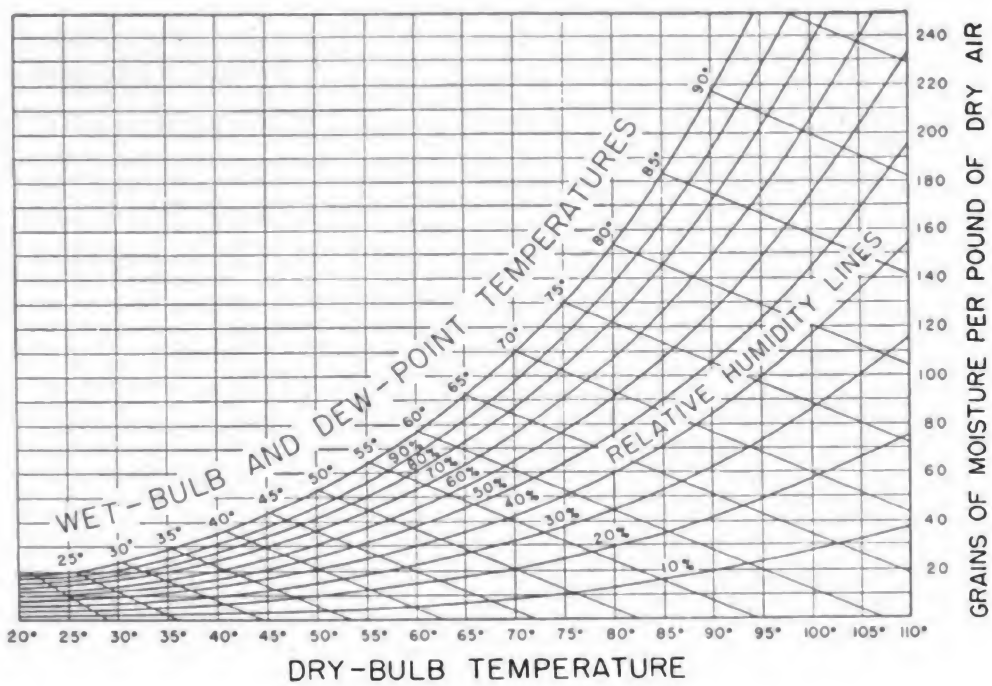


Figure 14–1.—Psychrometric chart.

lines of the unknown factors to their numbered scales and read the measurement.

Suppose the dry-bulb temperature were 70° F and the wet-bulb temperature 60° F, you would determine the dew-point temperature and the relative humidity in the following manner. Note the point of intersection between the dry-bulb and wet-bulb temperature lines. From this point, follow along the dew-point line (horizontal) to the dew-point scale. The dew-point temperature is approximately 54° F, the relative humidity is 56 percent (read by interpolating the reading at the intersection point between curved relative humidity lines).

If the dew point were to remain at 53.6° F, and the air were to be raised to the dry-bulb temperature of 80° F, what would be the relative humidity? Follow the dew-point line to the 80° F dry-bulb temperature line; at that point, the relative humidity is 40.5 percent.

If the dry-bulb temperature is 80° F and the dew-point temperature 70° F, what will be the relative humidity

when the dry-bulb temperature of the air is raised to 90° F? Note the point of intersection of the horizontal line running from the 70° F line with the vertical 80° F line. Follow this horizontal line to the 90° F dry-bulb line; at that point, the relative humidity reads 52 percent.

The actual weight of any amount of water vapor in air at any temperature can be read on the chart from the scale at the right-hand edge. Note the 70° F dry-bulb temperature line. From the intersection on the line of the various relative humidity percentage lines, follow the horizontal line to the right-hand scale, to read the number of grains of water vapor per pound of dry air. At the bottom is zero moisture, or completely dry air. At the top is 100 percent saturation. Such saturated air at 70° F holds a maximum of 110.5 grains per pound. The weight of water vapor that is contained in air at 70° F can be found, for any percentage of saturation, by starting with the given relative humidity point on the 70° F dry-bulb line, and following the horizontal line to the right-hand scale.

BODY HEAT BALANCE

Ordinarily the body remains at a fairly constant temperature of 98.6° F. It is very important that this body temperature be maintained, and since there is a continuous heat gain from surrounding and from interior processes, there must also be a continuous outgo to maintain a balance. This excess heat must be absorbed by the surrounding air. As the temperature and humidity of environment vary, the body automatically regulates the amount of heat which it gives off. However, this ability to adjust to varying environmental conditions is limited. Furthermore, although the body may adjust to certain atmospheric conditions, it may do so with a distinct feeling of discomfort. The discussion which follows will help you understand how atmospheric conditions affect the body's ability to maintain a heat balance.

Body Heat Gains

The body gains heat (1) by radiation, (2) by convection, (3) by conduction, and (4) as a byproduct of physiological processes that take place within the body.

The heat radiation gain comes from our surroundings, but since heat always travels from regions of higher temperature to regions of lower temperature, the body receives heat from those surroundings that have a temperature higher than 98.6° F. The greatest source of heat radiation is the sun. Indoor heat radiation is gained from heating devices, operating machinery, hot steam piping, etc.

The heat convection gain comes from currents of heated air only. Such currents of air may come from a galley stove or engine.

The heat conduction gain comes from objects with which the body, from time to time, is in contact.

Most of the body heat comes from within the body itself. Heat is being continuously produced inside the body by the oxidation of foodstuffs and other chemical processes, by friction and tension within the muscle tissues, and by other causes as yet not completely identified.

Body Heat Losses

There are two types of body heat losses; one is loss of sensible heat, and the other, loss of latent heat. Sensible heat is given off by three methods: (1) radiation, (2) convection, and (3) conduction. Latent heat is given off by evaporation. (Additional information on sensible heat, latent heat, total heat, and rate of heat generation may be obtained from chapter 38 of BuShips *Manual*.)

The body is usually at a higher temperature than that of its surroundings, and therefore radiates heat to bulkheads, decks, and equipment. This action is called heat radiation loss. The temperature of the air does not influence this radiation, except as it may alter the temperature of such surroundings.

The heat convection loss occurs when the heat is car-

ried away from the body by convection currents, both by the air coming out of the lungs and by exterior air currents.

The heat conduction loss is caused by bodily contact with colder objects or substances. Since the body is usually at a higher temperature than that of its surroundings, it gives up heat by conduction through physical contact with its surroundings.

The heat loss by evaporation is the loss of heat due to the cooling effect of evaporization of the body's moisture. Under normal air conditions, the body gets rid of excess heat by this method. The heat inside the body is sensible heat; during evaporation, it becomes latent heat. The rate of evaporation, and hence of heat loss, depends upon the temperature, relative humidity, and motion of the air.

When the temperature and relative humidity are not too high, and when the body is not too active, the body gets rid of its excess heat by radiation, convection, conduction, and a slight amount of perspiration. When engaged in work or exercise, the body develops much more internal heat, and perspiration increases. If the relative humidity is low, perspiration rapidly evaporates. However, if the relative humidity of the air is high, the moisture cannot evaporate, or it does so at a slow rate. In such cases, the excess heat cannot be removed by evaporation, and discomfort follows.

The amount of heat given off by the body varies according to the body's activity. When seated at rest, the average adult male gives off about 380 Btu per hour. On a ship, a man gives off an average of 500 to 600 Btu per hour.

For light work on a ship, particularly on a submarine, research has shown that the total amount of body heat loss is divided as follows: About 45 percent by radiation, 30 percent by convection and conduction, and 25 percent by evaporation. For normal body comfort, it is important that the heat loss be in these proportions.

If a person loses the same total of heat in the proportions of 40 percent by radiation, 50 percent by convection and conduction, and 10 percent by evaporation, he feels uncomfortable, damp, and chilly. This represents a condition of high relative humidity and too much air motion (a breeze from a fan or a direct draft). On the other hand, if the total heat loss is the same, but divided in the proportions of 30 percent by radiation, 25 percent by convection and conduction, and 45 percent by evaporation, a person will feel uncomfortable, hot, and parched. This represents a condition of low relative humidity and no air motion. It is apparent that while the total heat loss may be a desirable amount, it may be given off so as to produce distinct discomfort. To produce comfort, it is essential that the air conditioning be so controlled as to enable these heat losses to occur in the best proportions.

EFFECT OF AIR MOTION

In perfectly still air, a layer of air adjacent to the body absorbs the sensible heat given off by the body and increases in temperature. It also takes up the water vapor given off by the body and increases in relative humidity. The body is thus surrounded by an envelope of air which is at a higher temperature and relative humidity than the ambient air, and the amount of heat which the body can lose to this envelope is less than that which it can lose to the ambient air. If the air is set in motion past the body, the envelope is continually broken up and replaced by the ambient air, and the heat loss from the body is increased. When the increased heat loss improves the heat balance, the sensation of a "breeze" is felt; when the increase is excessive, the sensation of a "draft" is felt.

SENSATION OF COMFORT

From the foregoing discussion, it is evident that the three factors—temperature, humidity, and air motion—are closely interrelated in their effects upon comfort and health. In fact, a given combination of temperature,

humidity, and air motion will produce the same feeling of warmth or coolness as a higher or lower temperature in conjunction with a compensating humidity, and air motion. The term given to the net effect of these factors is known as the EFFECTIVE TEMPERATURE. This temperature cannot be measured by any instrument, but may be found on a special psychrometric chart when the dry-bulb and wet-bulb temperature and air velocity are known.

Though all of the combinations of temperature, relative humidity, and air motion of a particular effective temperature may produce the same feeling of warmth or coolness, they are not all equally comfortable. It has been found that a relative humidity below 15 percent produces a parched condition of the mucous membranes of the mouth, nose, and lungs, and increases susceptibility to disease germs. A relative humidity above 70 percent causes an accumulation of moisture in clothing. For best health conditions, a relative humidity ranging from 40 to 50 percent for cold weather, and from 50 to 60 percent for warm weather, is desirable. An over-all range from 30 to 70 percent is acceptable.

A COMFORT CHART, constructed to indicate the ranges of temperatures, relative humidities, and air velocities which produce a normal feeling of comfort for most persons, is illustrated in figure 14–2. This chart is for air velocities ranging from 15 to 25 fpm. You will note that the range of acceptable conditions for winter is different from the range for summer.

EQUIPMENT FOR SHIPBOARD AIR CONDITIONING

Each ship generally has an organization responsible for the operation, inspection, and maintenance of ventilating, heating, and cooling equipment. As an EN2, you may be a part of such an organization and should be familiar with certain elements of ship's air conditioning equipment.

Primary among the air conditioning systems installed

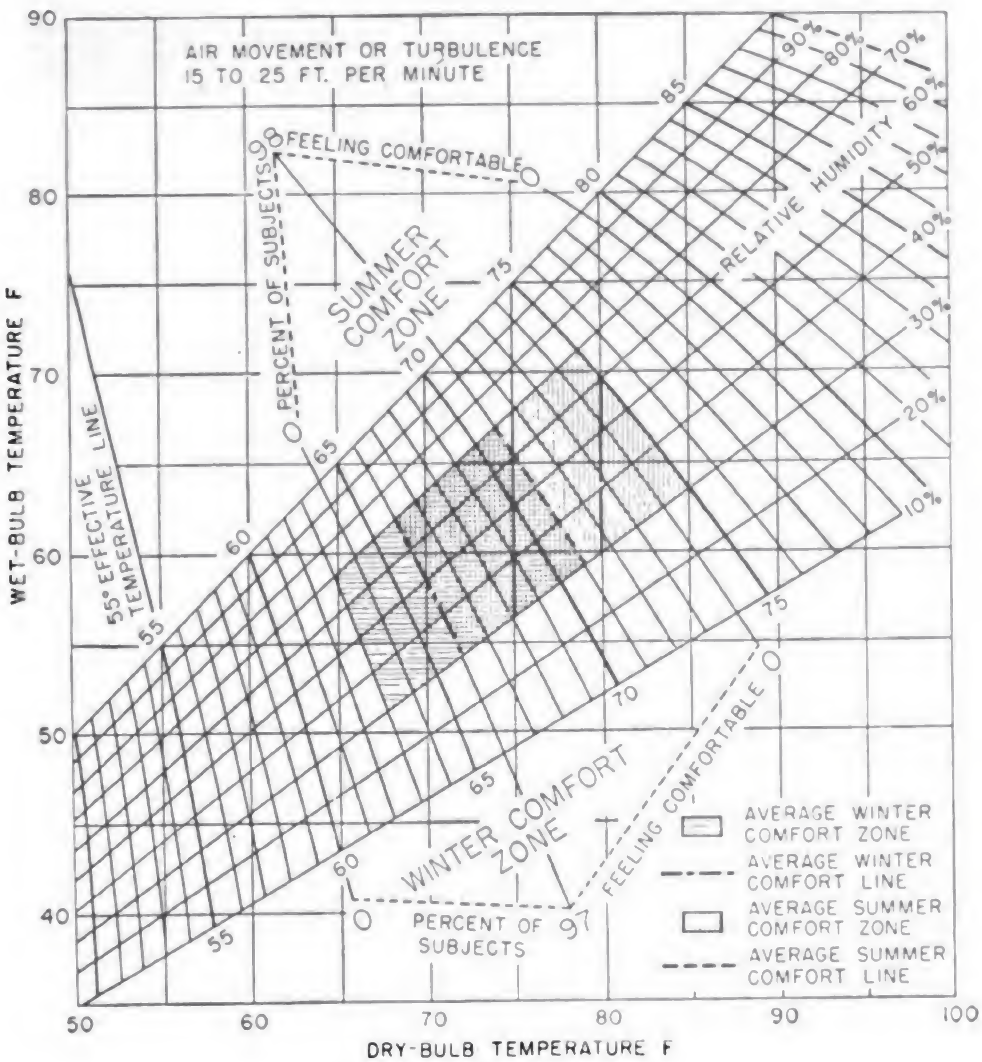


Figure 14–2.—Comfort chart.

aboard ship is that of the air duct distribution system. As the basic pipe lines for the other systems, the air ducts are utilized for cooling, ventilating, heating, dehumidifying, and purifying the ship's atmospheric air.

The arrangement of the air ducts throughout a typical naval surface vessel is illustrated in figure 14–3. The diagram indicates the location of the various units installed throughout the system for purposes of circulating, heating, cooling, and otherwise conditioning the air.

The number and location of mechanically cooled spaces vary in accordance with the ship's design and specifica-

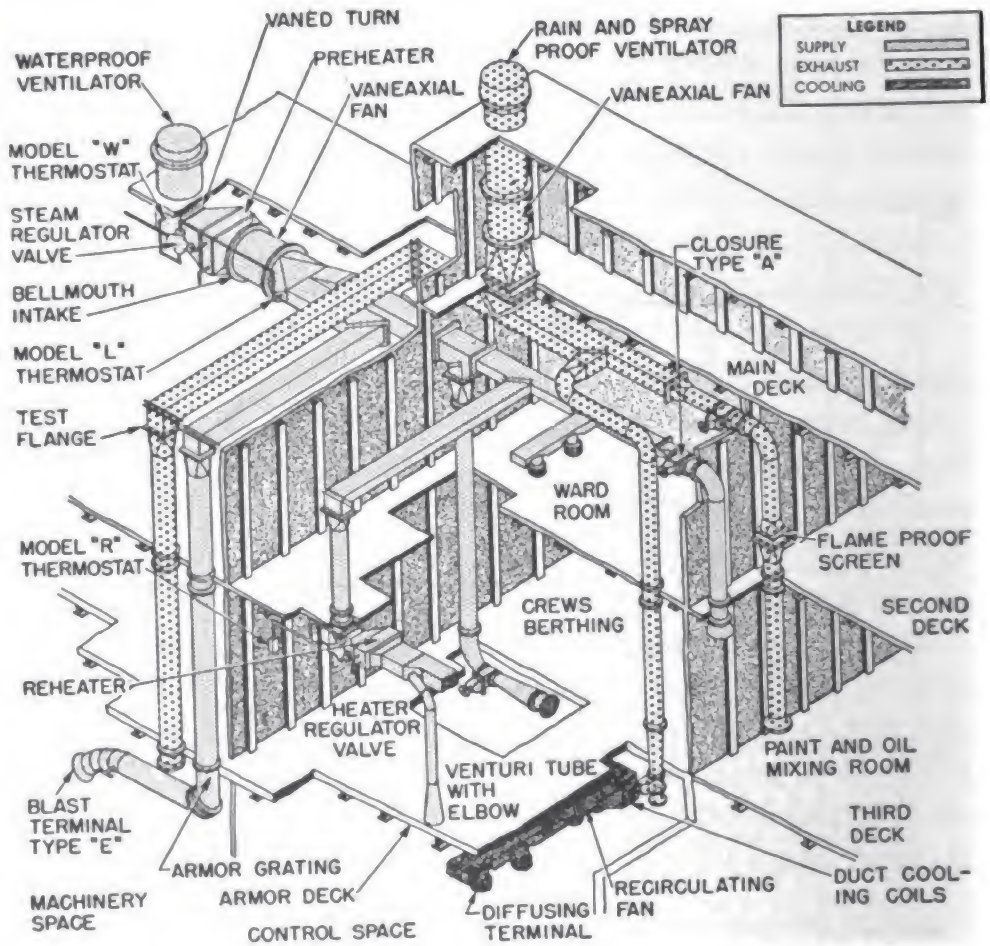


Figure 14–3.—Typical air conditioning duct arrangement of a modern naval surface vessel, showing locations of various units of equipment installed throughout the system.

tions, though this particular illustration shows but one such space. The tendency is to have more and more of the compartments of later ships mechanically air conditioned.

The waterproof ventilator, shown in figure 14–4, consists of an outer housing, an inner ventilator shaft extending up to the outer housing, and a bucket-type closure supported over the ventilator shaft by a compression spring. The bucket is provided with drain tubes extending into a sump between the ventilator shaft and the outer housing. The sump is provided with scupper valves, which drain onto the weather deck.

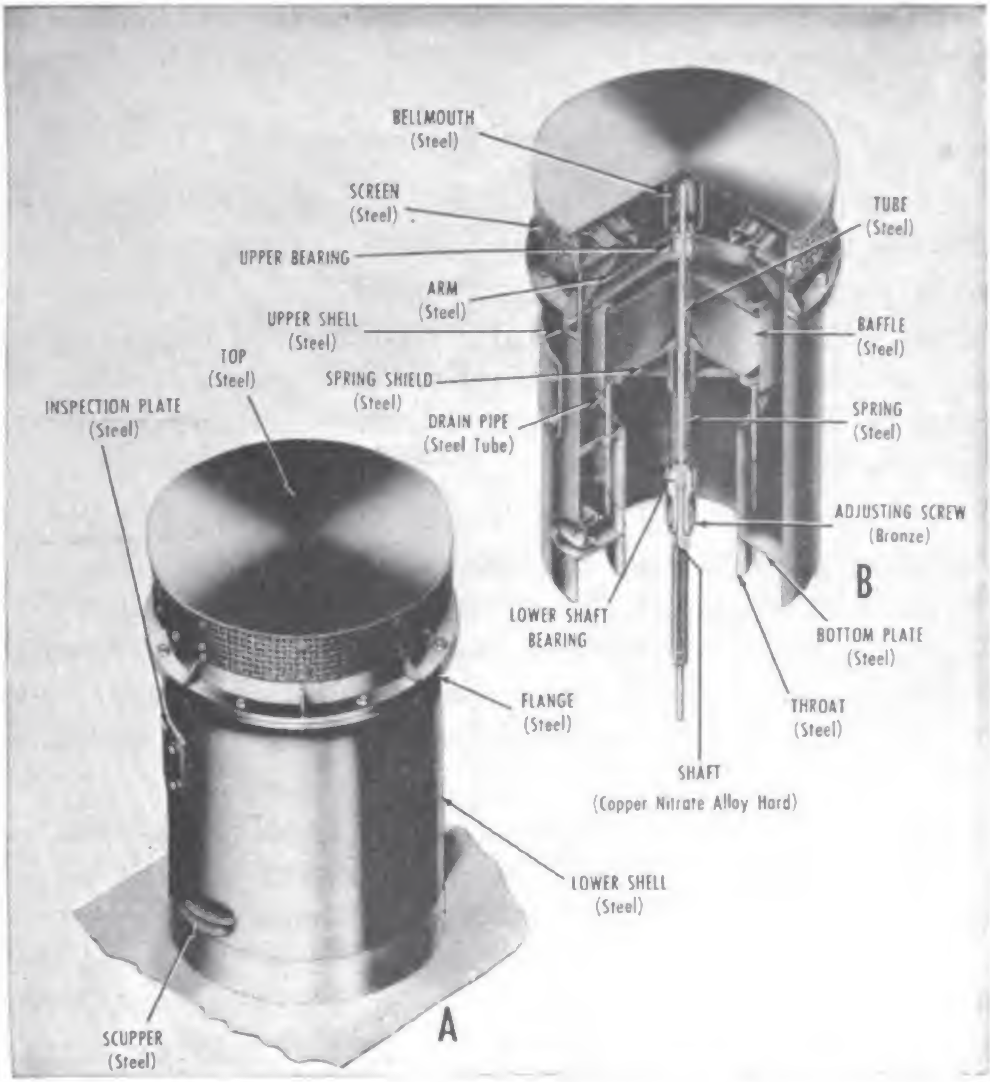


Figure 14–4.—Waterproof ventilator: (A) exterior view, (B) cutaway view.

The ventilator operates automatically, and is normally open. Small quantities of water which enter the ventilator fall into the bucket and drain out through the drain tubes and scuppers. In heavy seas, when water enters the bucket faster than it drains out, the weight of water forces the bucket down against the top of the ventilator shaft. Thus, a watertight seal is formed and maintained until sufficient water drains out to permit the force of the spring to raise the bucket to the open position. Operating gear is generally provided, also, to permit a manual closing of the ventilator. With slight variations in con-

struction, this ventilator is employed for both the suction and exhaust of air.

Ventilation Equipment

Since proper ventilation is the basis of all air conditioning systems and of related processes, information dealing with ventilation will be considered first. The sections which follow will contain information regarding the supply, circulation, and distribution of fresh air, and the removal of used, polluted, and overheated air from the various quarters.

AIR-CIRCULATING FANS. The fans employed in air conditioning systems are important units of the systems. By means of these units, the velocity of the air is controlled, the air is kept on the move, and is directed where needed. These fans include the vaneaxial supply and exhaust fans, or centrifugal fans, tubeaxial circulating fans, portable fans, and bracket fans.

VANEAXIAL VENTILATING FANS, built directly into the ventilating ducts (fig. 14–5), are axial flow fans which have been standardized in sizes, performance, characteristics, and over-all mounting dimensions for naval use. They are used for all installations where the pressures needed exceed those obtainable from tubeaxial or propeller fans. Since the motors for these fans (fig. 14–5) are designed for operation in a stream of air, the ducts should be left open when the fans are operated. The motors will overheat if they cannot move the air sufficiently to keep them cool. Dampers should not be closed to reduce the air flow more than 50 percent of the normal flow.

The standard TUBEAXIAL FANS (fig. 14–6A) are never used where more than one ventilator is required. For satisfactory operation in the duct systems, the higher pressure vaneaxial fans are always used.

The standard CENTRIFUGAL FANS (fig. 14–6B) are equally as efficient as the vaneaxial fans, but require bends in the air ducts wherever they are installed. (This dif-

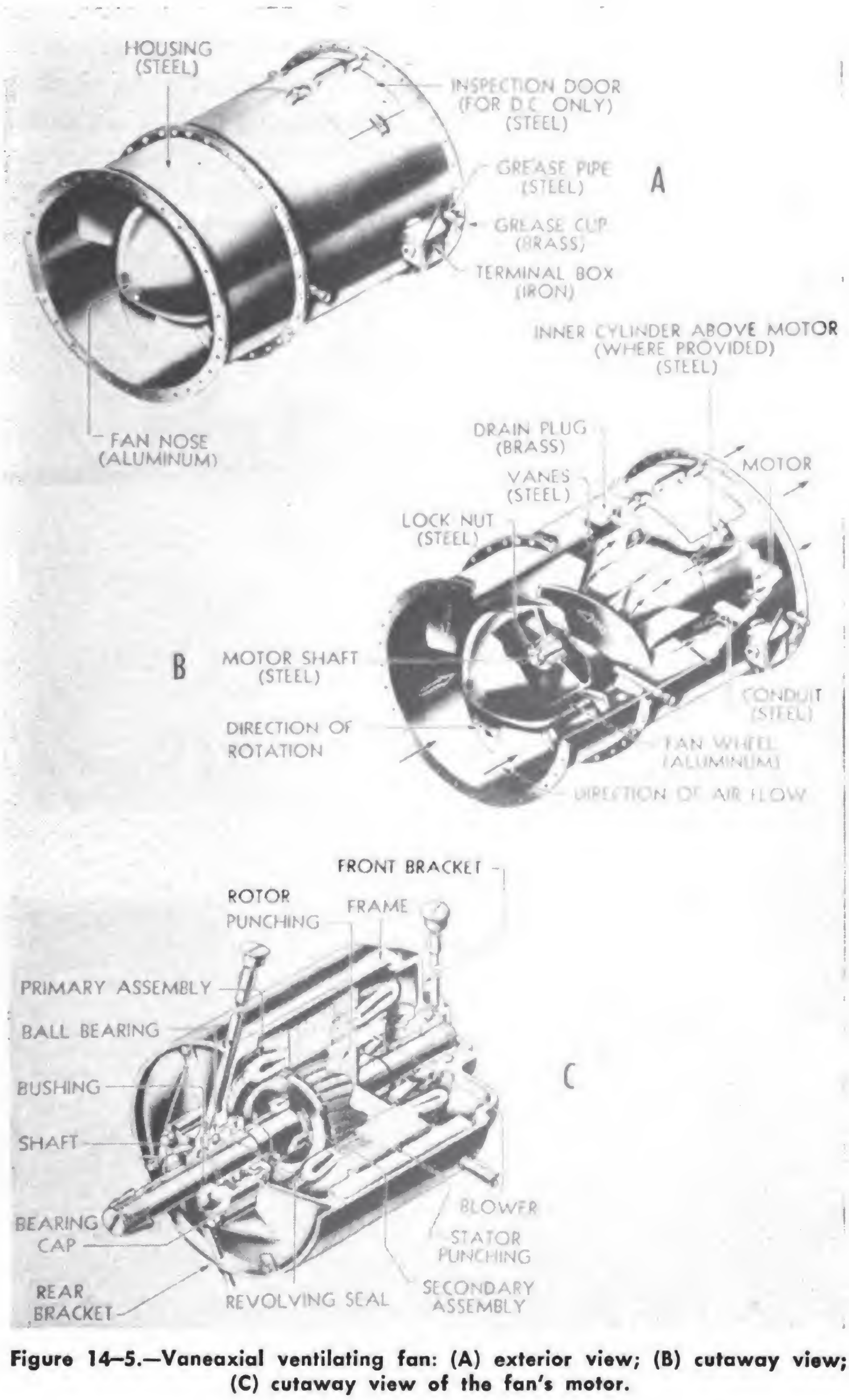


Figure 14–5.—Vaneaxial ventilating fan: (A) exterior view; (B) cutaway view; (C) cutaway view of the fan's motor.

ference factor is quite obvious from a study of the illustrations in figures 14–5 and 14–6B.)

The PORTABLE FANS (fig. 14–6C) are used aboard ship to ventilate compartments after painting, to exhaust

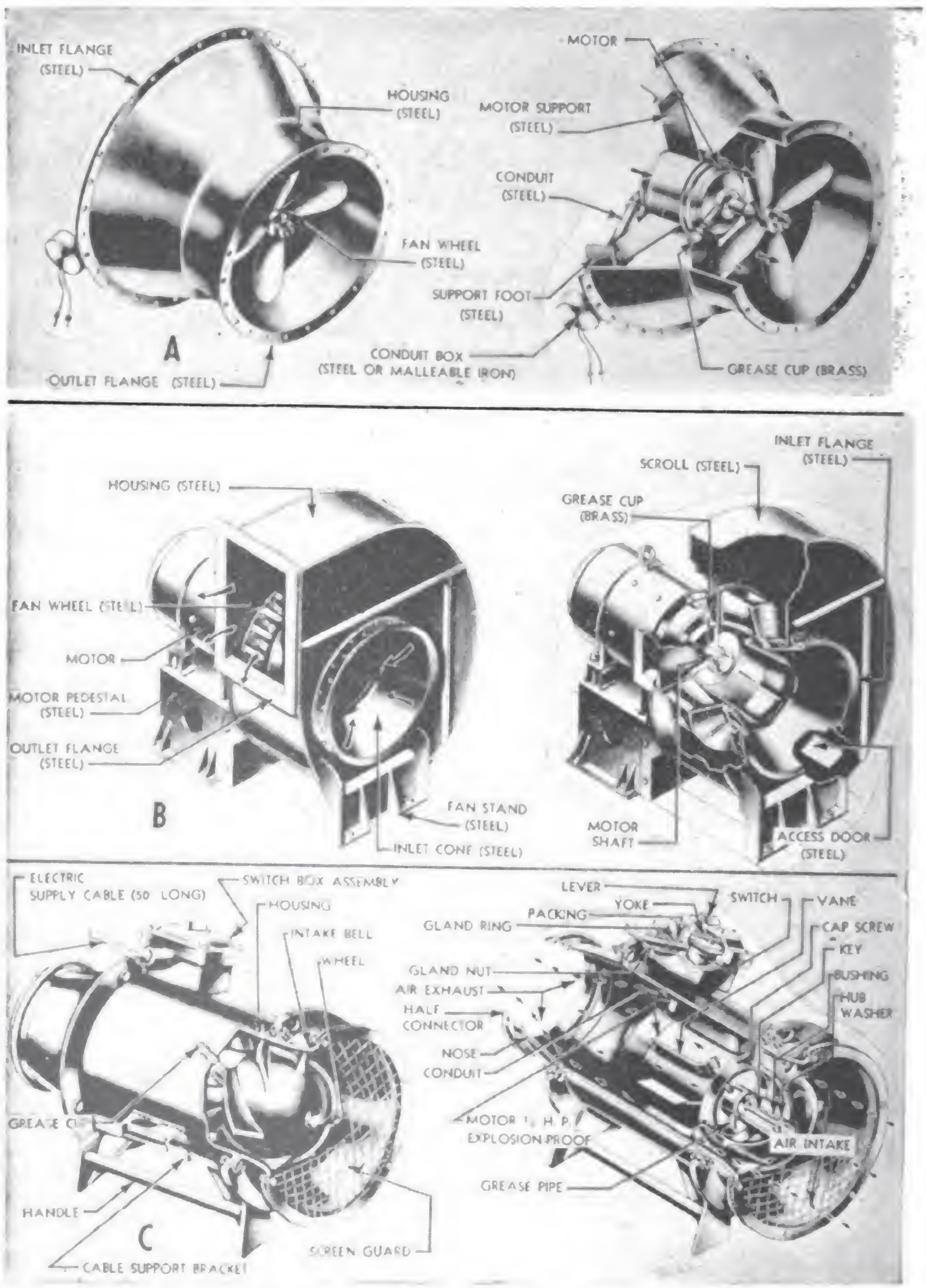


Figure 14–6.—Miscellaneous ventilating fans: (A) tubeaxial fan; (B) centrifugal fan; (C) portable axial fan.

flammable or toxic gases from closed spaces and tanks, to cool hot spots around machinery during repairs, etc.

The BRACKET FANS are used in hot weather to provide local circulation. These fans are usually installed in living, hospital, office, commissary, issuance, and berthing spaces. Where mechanical cooling is employed, the bracket fans are sometimes used to facilitate proper circulation and direction of cold air.

EXHAUSTS.—The exhaust of ventilated air may be accomplished either MECHANICALLY by fans, or NATURALLY by the weather, for those spaces which open to the weather. With the latter method, trouble is sometimes encountered because the exhaust air path to the weather is closed. Thus, when the hot air is not removed, the supply system cannot replace it with cool air from the weather. In most cases aboard ship, mechanical exhaust is employed.

The AIR IS MECHANICALLY EXHAUSTED through pantries, passageways, or directly from the space ventilated. It is necessary to keep these exhaust systems running at all times, to discharge hot air from the living areas—even though some spaces, such as pantries and galleys, are not continually occupied. The continuous operation of all exhaust systems becomes particularly important when ships are in wartime cruising condition, with air ports and accesses closed.

Mechanical Cooling Equipment

On the latest combatant ships, practically all parts of the ship, except machinery spaces, utilize cooling equipment. The system most commonly used is the mechanical compression system, using Freon-12. The component parts of a Freon-12 plant are the compressors, the condensers, the thermostatic expansion valve, the filters, and the coils. In general, the refrigerant cycle, machinery, equipment, and piping arrangements are the same as that of the shipboard refrigerating plant.

AIR-COOLING CYCLE.—Figure 14–7 illustrates graphically the cycle of air temperature and moisture changes in a typical mechanical air conditioning system. The purpose of the system is to maintain a constant air condition in the space *A* to be conditioned. The hot, moist air is drawn from this space through a duct by action of a fan, which causes this used air to be mixed with fresh air drawn from the outside *B* at point *C*. The fan blows the air over the cooling coils *E*, whose surfaces are cooled by the refrigerant flowing through the coils. These cold surfaces absorb the heat in the passing air, and condense the excess moisture in the air. The condensation drips into a drain beneath the coils. The resulting cool, dry air is then blown from the cooling coils, through the ducts *D*, to the space *A* being conditioned. Here the cool air absorbs the excess heat and moisture in the space, and the cycle is repeated.

Some of the used air of the conditioned space *A* is exhausted from the space at point *F*, to allow for the fresh air being drawn into the system at point *B*. The admis-

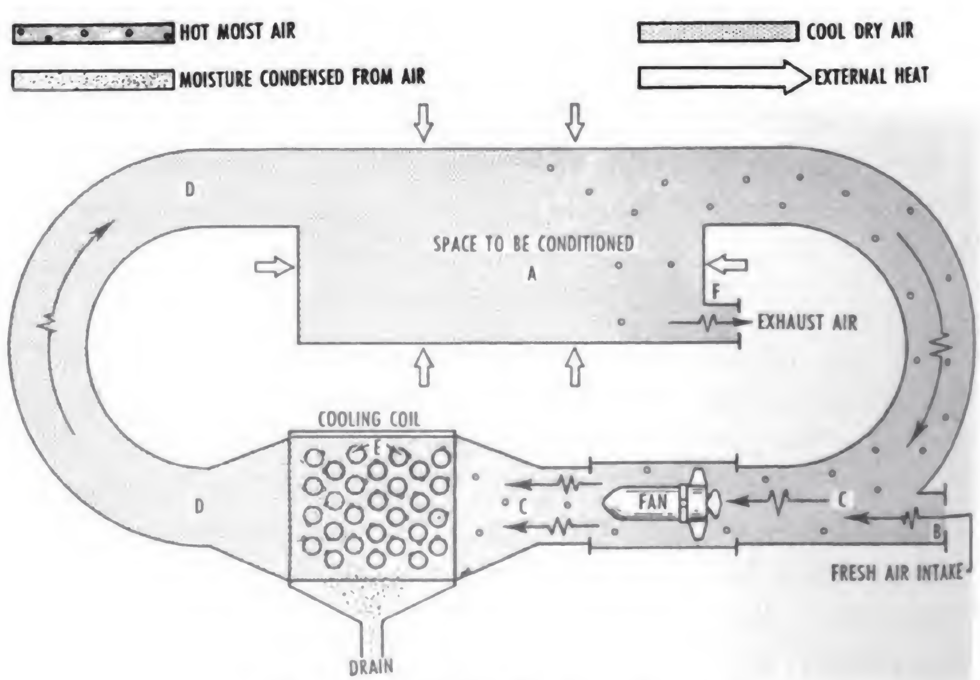


Figure 14–7.—Mechanical air-cooling cycle.

sion of outside or replenishment air at point *B* provides for the removal of odors, replenishment of oxygen, and dilution of carbon dioxide. The cycle continues as long as necessary to maintain the desired condition. The volume of conditioned air in space *A* is usually great enough to create a pressure sufficient to prevent inward air leakages.

MECHANICAL AIR-COOLING SYSTEMS. To determine what equipment will most effectively remove heat from compartment air—dehumidify as well as lower the temperature—the Navy has tested several types of air-cooling systems. Basically, these systems are refrigerating systems, their design and construction depending upon the characteristics of the cooling element circulated through the system and upon the principle of operation utilized.

There are, in general, three types of mechanical air-cooling systems employed by the Navy: the refrigerant circulating system, the chilled-water circulating system, and the unit cooler system.

A typical shipboard REFRIGERANT CIRCULATING AIR CONDITIONING SYSTEM is illustrated in figure 14–8. As you can see, the refrigerating plants of these systems are similar to those employed for the ship's regular refrigeration systems. By comparing this diagram with that of the ventilating air duct system, illustrated in figure 14–3, you can obtain a clear conception of this type of air-cooling system. The duct-type cooling coil indicated in figure 14–3 is the cooling element, or refrigerant evaporator, installed in the cooling ducts leading into the control space indicated in figure 14–3.

Some air conditioning systems have two interchangeable refrigerating plants, and the number of cooling coil units varies with the size of the ship and the number of compartments to be cooled.

The CHILLED-WATER CIRCULATING AIR CONDITIONING SYSTEMS are similar to the refrigerant circulating type systems as far as distribution of cooling coils, fans, and

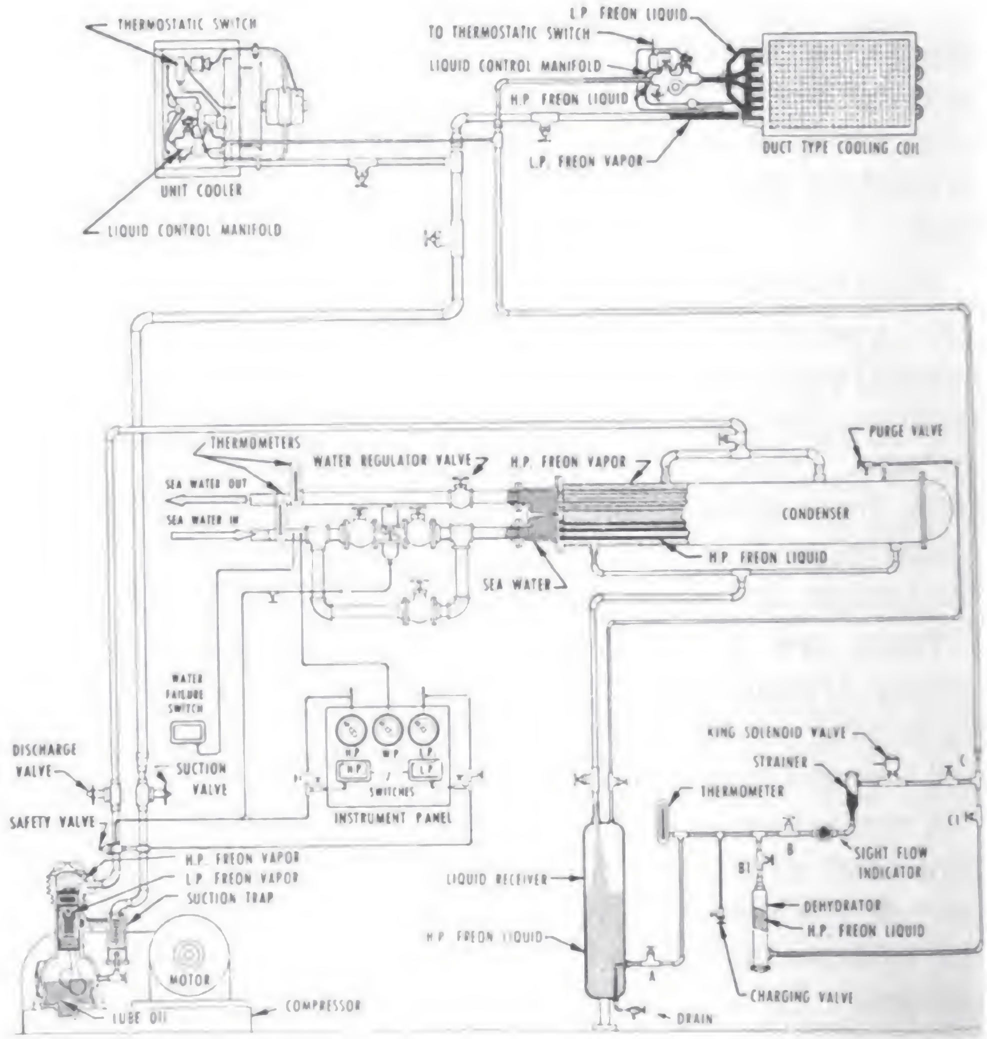


Figure 14–8—Typical shipboard refrigerant-circulating air conditioning system.

ducts are concerned. They differ, however, in that the cooling element is chilled water instead of Freon-12 refrigerant. This makes it possible to have all machinery parts in one space, and provides for a considerably simpler and less expensive operation because much more space can be conditioned with a minimum quantity of refrigerant fluid and gas.

The UNIT COOLER AIR CONDITIONING SYSTEM consists of a number of independent air conditioning units (or unit coolers) located in various compartments of the ship.

Types of Air Cooling Coils

Three types of plate-fin air-cooling coils are generally used for air conditioning systems of naval surface ships: duct coils, gravity coils, and unit cooler coils. The plate-fin coils used for refrigerant circulating and chilled-water circulating systems are similar, differing only in minor construction aspects.

The DUCT-TYPE AIR-COOLING COIL (fig. 14–9) is supplied

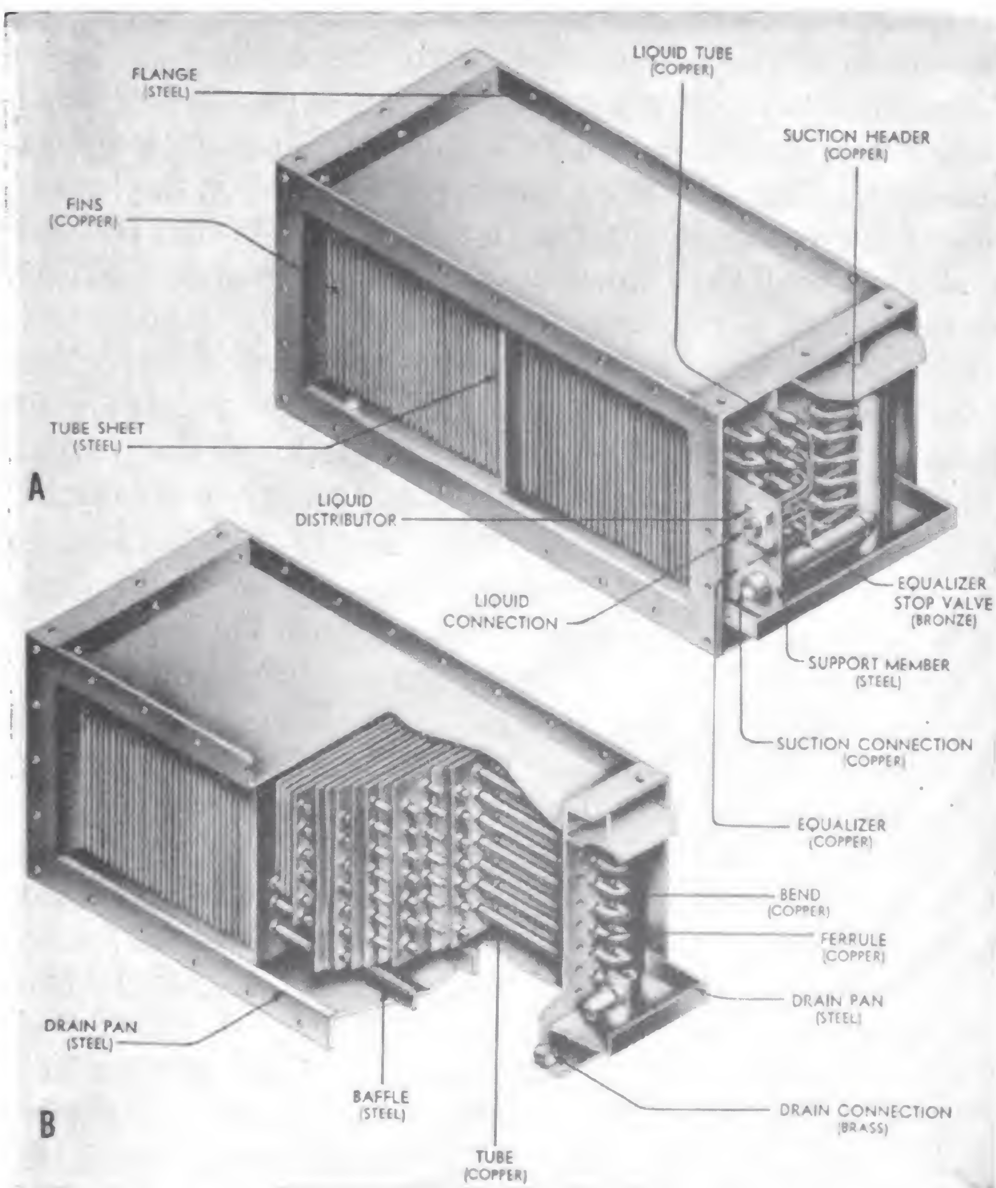


Figure 14–9.—Duct-type plate-fin air cooler: (A) exterior view; (B) cutaway view, showing arrangement of plate fins.

with a refrigerant control assembly to which is fitted a drip pan and drain. In some old installations, this assembly is mounted on an adjacent structure. The new series of coils have these controls on the unit; the related duct thermostat bulb is fitted within the air inlet duct. The coil tubing passes through plates or fins of thin metal (shown in inset of fig. 14–9), stacked seven to the inch the entire length of the coils. The air flow through the cooler is parallel to the fins, which are curved slightly to create a turbulent flow of the air. Thus, all the air is caused to come into contact with the cooling surfaces. Sometimes the coils are in two entirely separate sets, with each set being connected to a different one of two compressors. The coils are preferably installed on the intake side of the recirculating fan in the system, so that the coil inlet face is always open and free for cleaning. Slight deviations in air quantity from the cooling ducts will materially alter the performance of the system. The designated air quantities should be limited to a plus or minus 5 percent; therefore, it is best to know the proper operating speed for the recirculating fan in the air duct.

The GRAVITY AIR-COOLING COIL (fig. 14–10) is used in spaces where electrical equipment cannot be used or the installation is difficult, and for spaces with low heat loads to be removed. It is designed for overhead mounting, with a clearance of at least 4 inches between the overhead and the coil face. The drip pan is installed with a drain line discharging over a deck drain, or is located to collect the condensate into a container. Designated capacities of these coolers are increased 50 percent when bracket fans are mounted on two opposite sides of the coil, with the air drafts directed toward the coil. (A single fan will not result in an appreciable increase.) A number of gravity coils are sometimes installed on the same control set, to obtain the required capacity for the space. Since the solenoid control valve is electrically operated, it is sometimes necessary to locate the control manifold outside the spaces served by the gravity coils. In such cases,

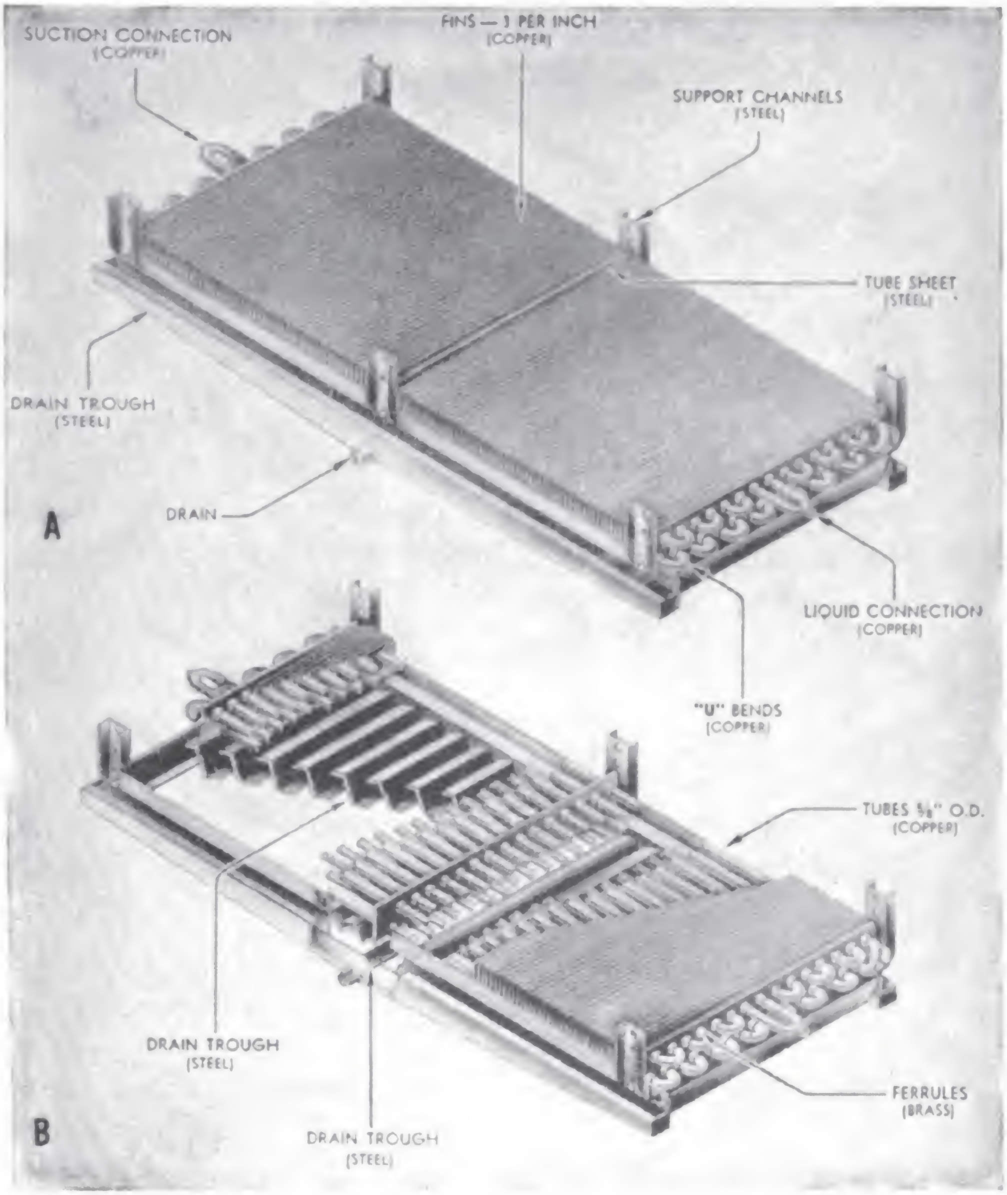


Figure 14–10.—Gravity-type plate-fin air cooler: (A) exterior view; (B) cutaway view.

the thermostat bulb must be led through the bulkhead and located in the conditioned space.

The UNIT AIR COOLER (fig. 14–11) is a compact cooling unit including the plate-fin coils, the motor-driven fan, the fabricated refrigerant controls, the thermostatic bulb and switch, and the control valve manifold. In order for these units to deliver their rated refrigeration tonnage,

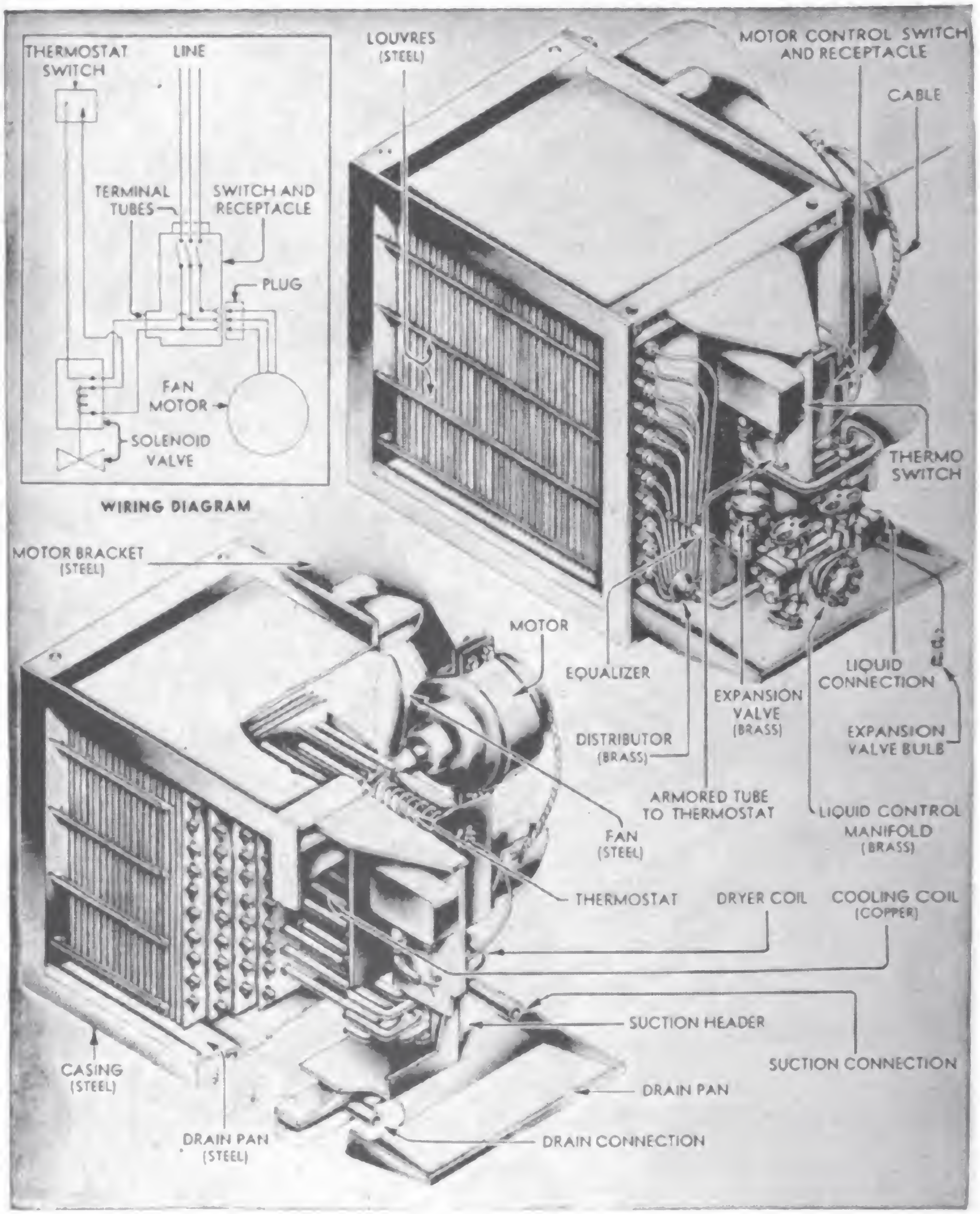


Figure 14–11.—Unit-type plate-fin air cooler.

air delivery over the coils must be maintained at the maximum capacity. A dirty coil face, or gauze, rigged across the air stream to act as a filter, will reduce the output to a small fraction of its potential capacity. (Modern coolers are equipped with filters.) The fan is easily demountable, thus facilitating the frequent cleaning of the fin tube inlet surface. Ducts should never be fitted on these coolers; any increase in the resistance pressure will reduce the air flow and result in an under capacity.

HEATING EQUIPMENT

In the sections which follow, consideration will be given to the heating systems and the various types of heaters used aboard ship.

HEATING SYSTEMS. In addition to the zone heating, central heating, and individual space heating types of steam heating systems, a direct heating system may also be employed.

A ZONE HEATING SYSTEM consists of a thermostatically controlled preheater and several automatically controlled reheaters. The heated part of the ship is divided into zones. Each zone consists of spaces which have approximately the same exposure, and each zone has a reheater. This system is more easily controlled than the central heating system (having dissimilar exposures), and has less weight and requires less space than the individual space system.

A CENTRAL HEATING SYSTEM has one preheater coil followed by one or more reheater coils. Air is blown through all coils and then distributed by ducts to spaces to be heated. The control may be totally manual, totally thermostatic, or thermostatic on the preheater and manual on the reheaters. (Manual control is found only on some older ships.) This system is found on older ships, or on later ships where a system serves only one compartment.

An INDIVIDUAL SPACE HEATING SYSTEM has one thermostatically controlled preheater for the system and one or more thermostatically controlled heaters in each space heated. Line heaters (located in the ducts) or terminal heaters (located at duct outlets) may be used. The preheater heats the air to approximate room temperature; the reheaters provide additional heat to compensate for heat loss within each space. In some cases, unit heaters are installed instead of the reheaters.

The DIRECT HEATING SYSTEM is employed for certain small spaces, isolated spaces, or spaces receiving indirect

supply ventilation from other heated spaces. Heater units may be used as convectors or electric heaters, and are controlled by occupants of the space.

Air-Heating Elements

VENTILATION HEATERS (fig. 14–12), installed within the ventilation ducts, are used whenever practicable because of a saving in weight, space, and piping. These heaters are built to withstand considerable shock, and have standard connections to simplify the piping. The copper tubes, through which steam flows, are arranged in a single row; when more than one row of tubes is required to obtain the designed temperature rise, several heaters may be stacked (one over the other, or end to end) in the direction of the air flow.

The tubes may be arranged in various ways. Figure 14–12B shows the S arrangement, with 5/8-inch copper tubing serpentined; figure 14–12C shows a T arrangement, with parallel double copper tubing (a 3/8-inch distributing tube inside a 5/8-inch outer tube) leading into a header. Copper fins, arranged on both sides of the tubing, aid in the transfer of the heat to the air flow. Steam working pressures up to 150 psi may be used in these heaters.

The coil with the closer fin spacing is installed downstream, to prevent dirt from accumulating in the inaccessible area between the coils. When it is necessary to replace a ventilation heater, the replacement should have the same face area (finned space) and shape, the same number of fins per lineal inch of tube length, and the same number of rows of tubes in the direction of air flow.

Ventilation heaters are usually installed in two sections—a PREHEATER section and a REHEATER section. Preheaters are generally installed near the intake to heat the supply of air sufficiently to prevent condensation on ventilation ducts—sweating on the outer surfaces of the cold ducts. If this preheat temperature is allowed to get

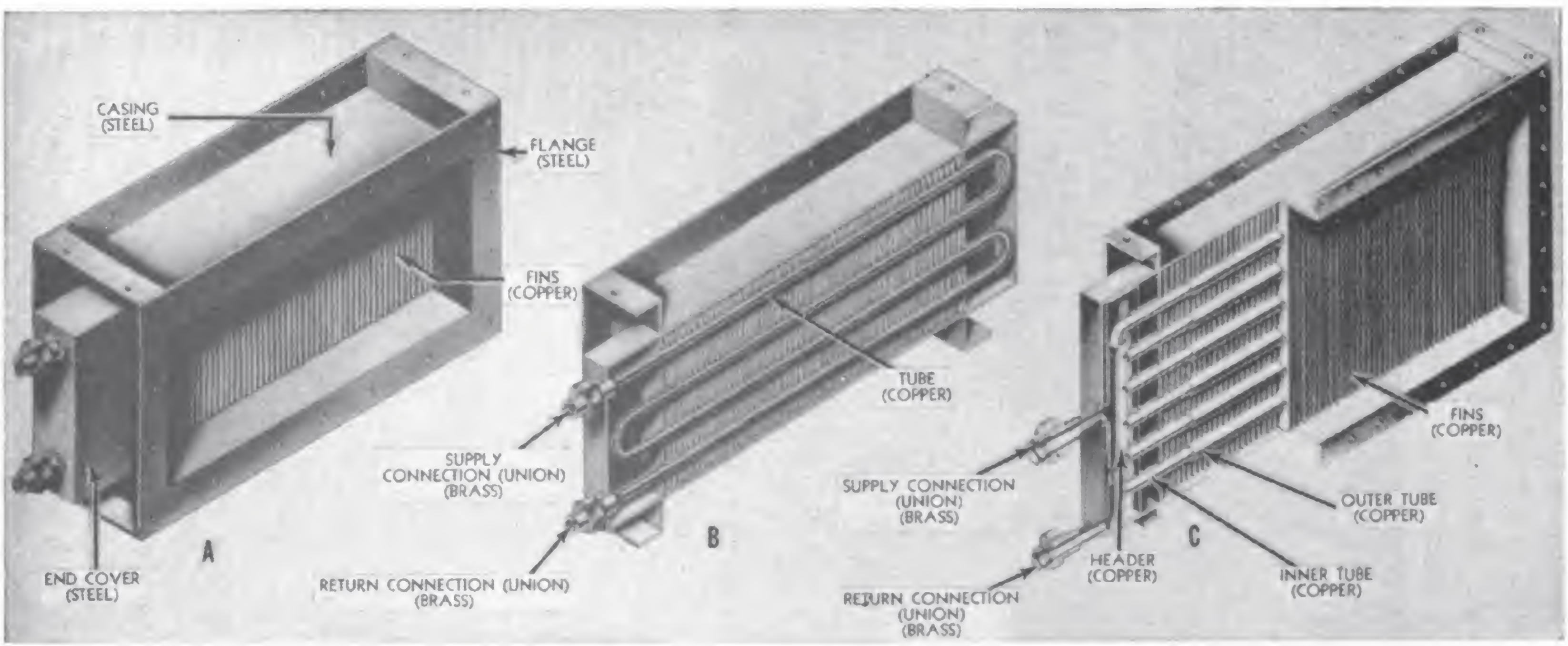


Figure 14–12.—Ventilation heaters: (A) exterior view of S-type heater; (B) tube arrangement of S-type heater; and (C) tube arrangement of T-type heater.

too high, the inboard spaces that are completely protected against outside conditions will be overheated.

Preheater regulation is accomplished both automatically and manually. The latest automatic control consists of two regulating valves, either in a single valve body or as separate valves. One valve has a capacity of 25 percent of the heat, and is thermostatically set to open at 35° F; it is located in the weather duct on the inlet side of the heater. The outer valve, with a capacity of 75 percent of the heat, is thermostatically set to maintain the desired discharge air temperature (usually between 45° F and 65° F), and is located in the duct on the discharge side of the heater. If heating is reported to be unsatisfactory, and the heater coils are clean, the location and operation of the thermostat regulators should be checked. (Proper settings can be found in the ship's General Information Book). When the weather temperature falls below 37° F, the MANUALLY OPERATED STEAM VALVES, supplying all preheaters on the ship, must be turned on to prevent the coils from freezing.

Reheaters are provided to increase the air temperature to the degree necessary to properly heat spaces exposed to the weather—that is, with doors opening to the outside or to other spaces which have such exposures.

CONVECTOR HEATERS (fig. 14–13) are installed in small spaces or in spaces which are not fitted with mechanical supply ventilation. These heaters have a high heating capacity for their size and weight, are considerably smaller than radiators or pipe–coils of the same capacity, and will withstand severe shock. A steam pressure up to 150 psi may be used in the heaters, or a forced hot water system may be employed. When they are used with steam pressure between 25 and 50 psi, temperature differentials at different levels in the room are reduced. The heating is regulated with the air bypass damper in the front part of the heater. The cabinets are generally of steel, though they may be, (if desired) of copper of a nonmagnetic construction.

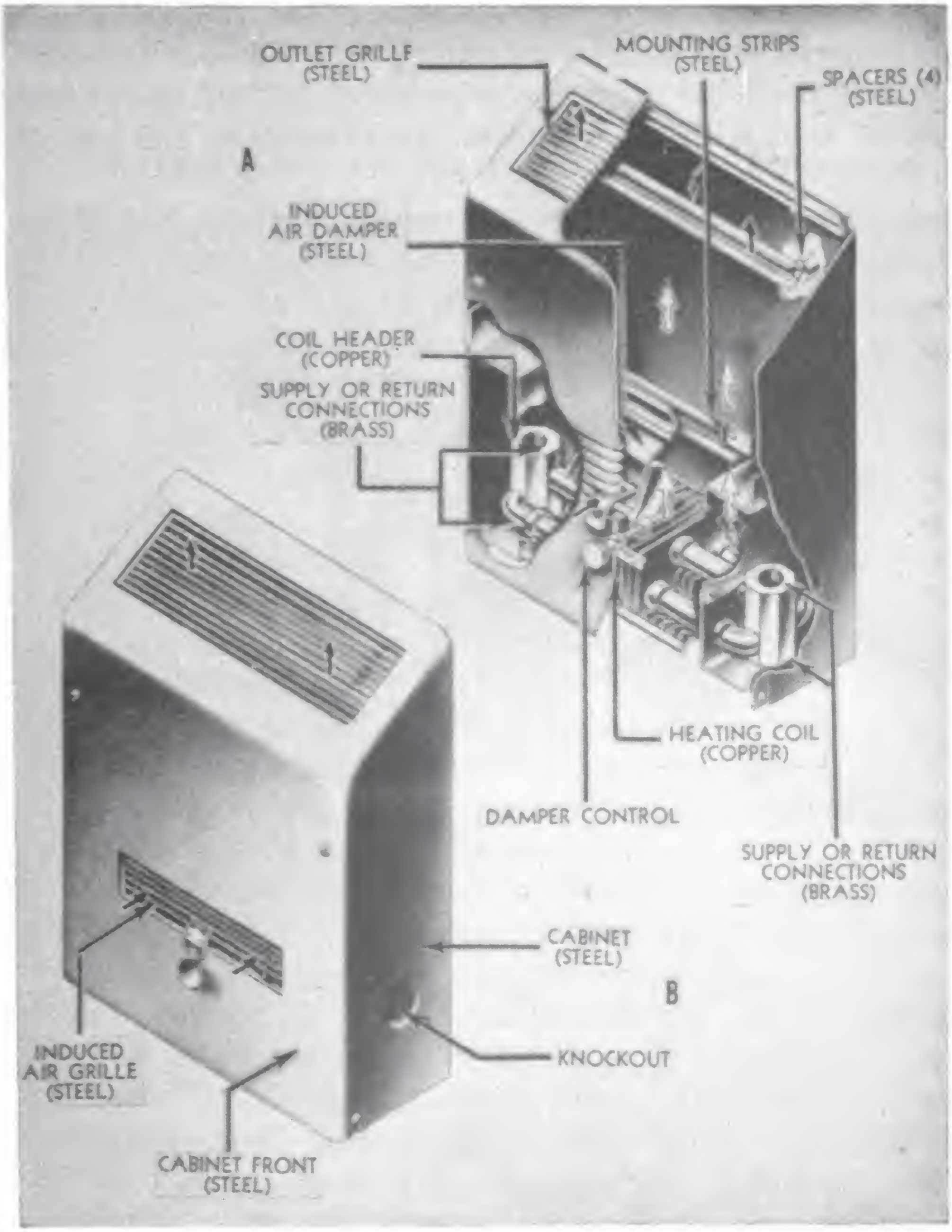


Figure 14–13.—Convector heater: (A) cutaway view; (B) exterior view.

UNIT HEATERS, illustrated in figure 14–14, are actually ventilation heaters installed separately with their own fans. They are used in special cases such as when the amount of supply ventilation is too small to provide sufficient heat through ventilation heaters, or where there is no mechanical ventilation supply and the heat requirements exceed the capacity of convector heaters. They can be used with either steam pressure up to 150 psi or

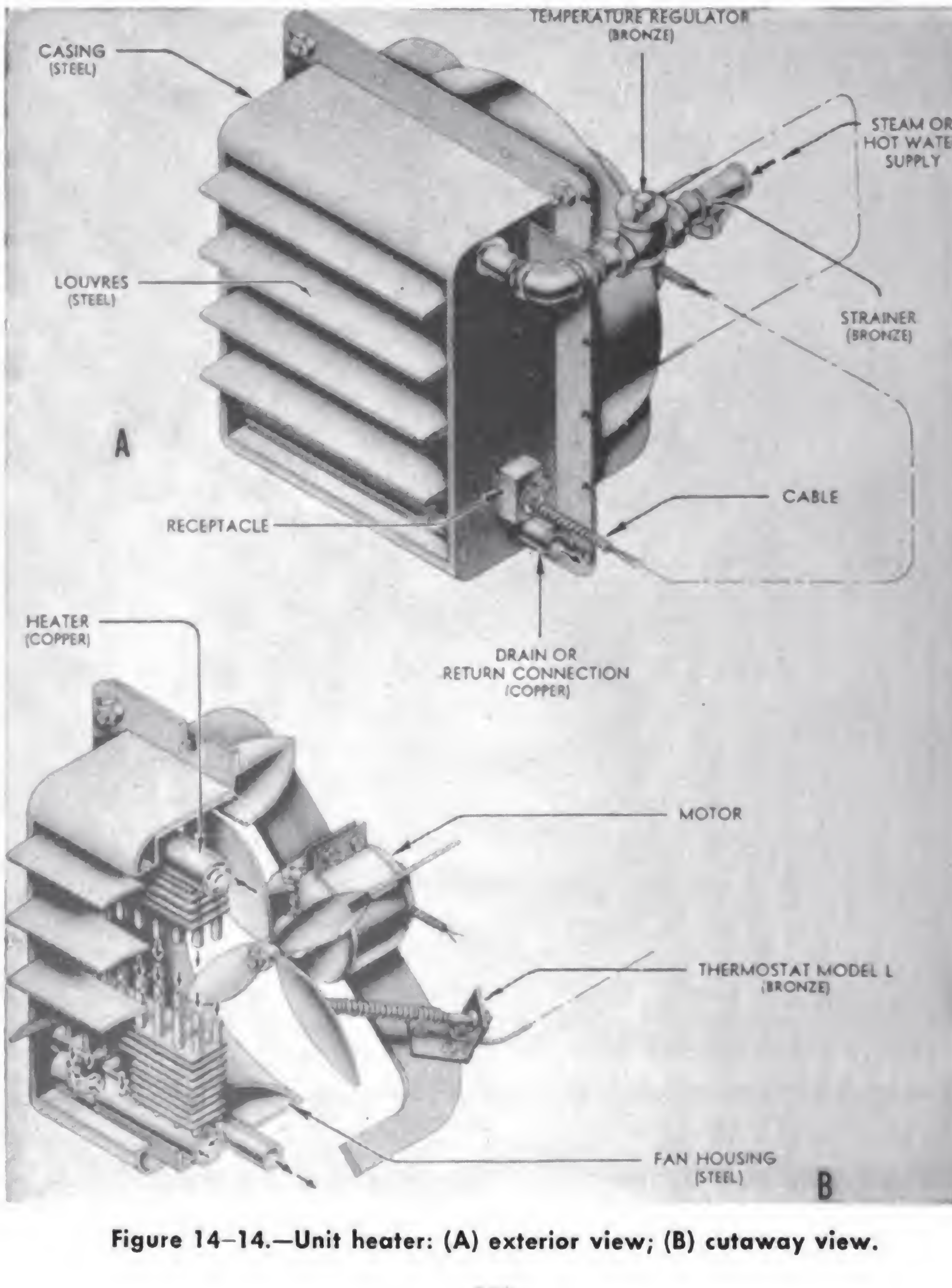


Figure 14–14.—Unit heater: (A) exterior view; (B) cutaway view.

with forced hot water systems. Composite parts of the heaters include the tubing, heat transfer fins, fan, thermostatic control valve, strainer, trap, and heat direction blowers.

ELECTRIC HEATERS are used for space located at a considerable distance from the steam piping system. They are built in many types and designs.

MAINTENANCE OF AIR CONDITIONING EQUIPMENT

To ensure proper operation of any air conditioning system, periodic inspection and maintenance is absolutely necessary. Each ship should have an organization responsible for the maintenance of ventilating, heating, and cooling equipment.

Ventilation Equipment

Shipboard ventilation must serve not only to supply, circulate, and distribute fresh air, but also to remove the used, contaminated, and overheated air from the various spaces. If the ventilation equipment fails to perform its functions properly, conditions may be created which will jeopardize the health or life of crew members. Therefore, the individuals responsible for inspection and maintenance must be thoroughly familiar with the ventilation equipment.

A shipboard ventilation system and its constituent parts cannot be isolated and separated from other component systems in a complete air conditioning system. For example, the air duct distribution system of a ship may be utilized for other systems used in cooling, heating, and dehumidifying the ship's atmospheric air. In addition to ducts, a ventilation system may include weather openings, screens, filters, fans, gratings, closures, heaters, cooling coils, venturi tubes, dampers, and terminals. Obviously, if a ventilation system is to function effectively, it is essential that all of its various units be kept clean and in satisfactory operating condition. To maintain a ventilating system in the best condition requires the observance

of applicable precautionary measures, and the adherence to prescribed maintenance procedures.

GUARDING AGAINST OBSTRUCTIONS TO VENTILATION.—Such items as swabs, deck gear, and trash stowed in fan rooms or ventilation trunks not only restrict air flow but also increase dirt and odors taken inboard. Ventilation terminals must never be used for stowage. Wet clothing secured to ventilation terminals increases the moisture content of the compartment air, and restricts the air flow. Stowage arrangements should be such that ventilation weather openings and forced draft blowers are never restricted.

Do not use gauze or similar material as a filter over an air supply terminal. Gauze may aid in preventing the passage of dirt but it also serves as an obstruction to the passage of air. The fact that filtering is necessary indicates that the system needs cleaning. The amount of dirt entering a space from the ventilation system can be most effectively reduced by keeping the ducts clean. If it becomes necessary to place a filter in an air supply system, place the filter at the intake rather than supply terminals.

KEEPING THE SYSTEM CLEAN.—Dirt accumulations in a ventilation system not only restrict the flow of air but also create a serious fire hazard. In a clean duct the cooling effect of the metal tends to act as a flame arrester, but an accumulation of foreign matter within a duct becomes a potential source of combustion. One method of reducing the amount of dirt and combustible matter which may be carried into a ventilation system is to wet down the areas in the vicinity of the air intakes before sweeping.

Since a great volume of air passes through or over the elements of a ventilation system, dirt will collect in the various units in spite of precautionary measures. The greatest accumulations of dirt will be within trunks and ducts where it is not readily noticeable. Therefore, periodic inspections and a definite service procedure are necessary to keep the system clean.

All screens, flame arresters, cooling coils, unit coolers, unit heaters, and duct-type heaters should be cleaned at least one each week, unless protected by filters. Protected equipment should be cleaned as often as necessary. Filters are generally cleaned at least once each week. Operating conditions or the type of work being conducted in a space may make more frequent cleaning of filters necessary. For example, the grease filters in a galley should be cleaned once a day. A ventilation system, from the weather end to the last branch, should be thoroughly inspected twice a year and cleaned as necessary.

CLEANING INSTRUCTIONS. As mentioned previously, many of the units which make up a ventilation system may also be listed as part of an air conditioning system. Therefore, the following instructions apply to the units as a part of an air conditioning system and not specifically as ventilating elements.

When preparing to inspect or clean a heating, cooling or ventilating system, make a check sheet, listing the coils, filters, flame arresters, and screens contained in the system(s), to ensure that no important part is overlooked.

To clean the heating or cooling coils, proceed as follows:

1. Stop the fan.

2. Open the access plates on all coils of the system.

3. Brush the intake side of the coil to loosen lint and dirt. A special tool with teeth spaced to fit between coil fins will remove caked accumulations. Wire brushes may be used on Navy standard plate-fin coils, but the brush must be carefully handled to avoid damage to the fans.

4. Vacuum the intake side of the coil.

5. Blow compressed air through the coil from the discharge face where necessary, and vacuum again.

6. Examine the surfaces of the fins and tubes. If a considerable film of grease and dirt is found, the coil should be washed with a recommended cleaning agent.

The agents recommended for cleaning coils are nontoxic and they can be safely used in closed compartments if exhaust ventilation is in operation. However, remember that the cleaning agent is volatile, and when it is used on cooling coils the compressor must not be shut off. Before using the agent on heating coils, shut off the source of heat, and allow the coil to cool to room temperature before you apply the agent. If the condition of a coil warrants the use of a cleaning agent, the procedure for preparing and applying the solution is as follows:

1. Prepare an adequate supply of cleaning solution, using four ounces of detergent (N.D. Specification 51C20) per gallon of warm water (about 100° F).

2. Wet down the entire coil surface, using a fine but slow spray. Work from the air discharge side of the coil.

3. Allow the coil to stand for about five minutes.

4. Wash the coil with clean water, using a spray of very high velocity. Apply the spray from the air discharge side to the air inlet side of the coil. If necessary, provide a means to prevent the dirty solution from being carried past the coil into the supply duct.

5. Drain off and wipe away any remaining solution.

6. Allow the coils to dry before the access plates are replaced.

The cleaning of SCREENS involves securing the fan and using a vacuum cleaner equipped with a stiff brush.

The proper cleaning of a FLAME ARRESTER (cell type) requires that the cell be removed from the housing. Compressed air should be blown through the cell from the air discharge side and a cleaning solution should be used when necessary. Do not tap the frame or the wire mesh of a flame arrester cell to loosen dirt. When an arrester cell is replaced, see that it is in the proper position with respect to air flow; also make certain that the housing bolts are properly tightened, in order to make the arrester flametight and watertight.

Flame arresters on most recent installations are equipped with air filters. Proper maintenance of these filters will eliminate the need for frequent cleaning of the arresters.

In an air-cooling system, the FILTERS are cleaned by removing them and tapping the frames on a hard surface to loosen the dirt. Then compressed air is blown through the filters from the air discharge side and a cleaning solution is used as described in the cleaning instructions for coils.

Heating Equipment

With respect to care and maintenance, several of the elements used in the heating phase of air conditioning have already been discussed. The need for periodic inspections and frequent cleanings also applies to other parts of a heating system. Because of the variety of heating systems (zone, central, individual space, or direct), any one or all of which may be used aboard ship, and the variety of air-heating elements (ventilation, convector unit, or electric) and other parts essential in the heating process, the details of maintaining a specific heating system or any of its component parts must be obtained from appropriate maintenance instructions.

However, it is important for you to know that malfunctioning of heating systems (including convectors and radiators) is frequently caused by inoperative steam traps. The thermostatic bellows type is the one most commonly used. A ruptured bellows may result in a serious unbalance in the entire steam pressure relationship between various heating units, since steam blowing through the drain line causes a back pressure against which properly functioning traps cannot discharge. Consequently, the whole system may start banging and popping, and the water hammer action may be serious enough to rupture a heater tube. If there is no obvious cause for poor drainage (such as closed valves) in a heat-

ing system, an inspection of the steam traps should be made at once.

Cooling Equipment

Since air-cooling systems are, in many ways, similar to shipboard refrigerating plants, much of the information concerning refrigeration, as given in this training course, is equally applicable to air-cooling equipment. Some of the differences that exist between refrigerating and air conditioning equipment are included here, along with general maintenance information.

COMPRESSORS.—The reciprocating compressors of air-cooling systems are similar to the refrigeration system compressors. The sizes of these units vary in accordance with the capacity required.

Operating suction pressures and evaporator temperatures used in Freon-12 air-cooling systems are higher than those used in refrigeration systems. This difference in suction pressure results in a corresponding effect on the rated capacity of the compressor. More refrigerated tons are developed at a higher suction pressure, and at a higher evaporator temperature.

A Freon-12 compressor should not be allowed to remain idle for an extended period of time. Idle compressors should be operated at least once a week. If a plant includes a duplicate or standby compressor, it should be operated alternately with the main compressor, changing from one to the other at least every week.

THERMOSTATIC EXPANSION VALVE.—In air-cooling installations, the external equalizer is used with the thermostatic expansion valve, in place of the internal equalizer. The internal equalizing port between the valve outlet and the spring chamber is eliminated; instead, there is an opening through the valve directly into the spring chamber. By means of a copper tubing the spring chamber is connected to the evaporator coil, beyond the point of greatest pressure drop. The external equalizer is used because in the air-cooling system there would be

an objectionably large pressure drop between the two ends of the cooling (evaporator) coils. This pressure drop is due to the fact that the tubing used is smaller, and the bends in the unit coolers restrict the flow through the evaporator.

The thermostatic expansion valve should operate without any difficulty if the system is kept free of moisture, dirt, or other foreign matter. Any foreign matter between the seat and the stem will prevent the valve from closing tight. Presence of moisture in the system may cause a freezeup at the valve port and block the passage of the refrigerant.

Since the thermostatic expansion valve is a delicate instrument, it should be handled carefully. If adjustment or testing of the valve is necessary, qualified personnel should follow the procedures specified in chapter 59 of BuShips *Manual,* or in the manufacturer's instruction book.

FILTERS AND COILS. Information concerning the inspection and cleaning of cooling units has been given in this chapter under the discussion on ventilation. The necessity for periodic inspections and cleaning cannot be overemphasized. It should be remembered that on installations not equipped with filters the air flow through the finned coils deposits a linty, matlike accumulation at the air intake side of the coils. If not removed, such an accumulation would result in a marked decrease of air flow over the coils and a great reduction in the unit's cooling capacity. Dust, organic material, and grease can also form a film on the entire cooling surface, thus reducing the rate of heat transfer and creating a source of objectionable odors. Therefore, the coils should be inspected periodically and cleaned as often as necessary.

SUMMARY

In this chapter you have been given general information on the principles, equipment, and processes of air conditioning as they pertain to the ventilating, cooling,

and heating of the ship's atmosphere. Detailed information concerning the operation and maintenance of air conditioning equipment may be obtained from chapter 38 of BuShips *Manual.*

An understanding of the psychrometric chart and the relationships between the dry-bulb, the wet-bulb and the dew-point temperatures is important in the operation and maintenance of air conditioning equipment. In addition, you should know the general arrangement of the air duct system; how ventilation systems are adapted to various compartments of the ship; and the various types of cooling and heating systems used by the Navy.

For efficient operation of air conditioning equipment, periodic inspections and maintenance are absolutely necessary.

QUIZ

1. What effect does a rise in air temperature have upon the air's capacity to hold moisture?
2. What is relative humidity?
3. A mixture of dry air and water vapor contains what kind(s) of heat?
4. What is the difference between the dry-bulb and the wet-bulb temperature called?
5. Within a compartment, when will the wet-bulb, dry-bulb, and dew-point temperatures all be the same?
6. Given a dry-bulb temperature of 80° F and a dew-point temperature of 70° F, what will be the relative humidity of the air if the dry-bulb temperature is raised to 90°F?
7. What are 4 ways by which the body gains heat?
8. When a man is performing light work aboard ship, how is the total amount of heat loss divided, for normal body comfort?
9. What term is used to describe the combined effect of the temperature, humidity, and air motion factors?
10. For best health conditions, what is the acceptable range limit of relative humidity during the winter?
11. What is used to illustrate the ranges of temperatures, relative humidities, and air velocities which produce a normal feeling of comfort for most persons?

12. What is the purpose of scupper valves on the waterproof ventilators?
13. What type fans are installed in the ducts of air conditioning systems?
14. What 3 types of mechanical air-cooling systems are generally employed by the Navy?
15. What 3 types of cooling coils are generally used for air conditioning systems of naval surface ships?
16. What type heating system consists of a thermostatically controlled preheater and several reheaters?
17. What specifications are required for any ventilation heater to be installed as a replacement?
18. What is the purpose of preheaters in a duct-heating system?
19. What type heaters are installed in small spaces or in spaces which are not fitted with mechanical supply ventilation?
20. What type heaters can be used with either steam pressure up to 150 psi or with forced hot water systems in spaces where there is no mechanical ventilation supply?
21. In addition to restricting air flow, what objection is there to using fan rooms or ventilation trunks for stowage, of such items as swabs and trash?
22. When preparing to clean the heating and cooling coils of a given system, what should be done before the fan is stopped?
23. What should be done if the use of a brush or similar tool and vacuum fails to remove the film of dirt from the fins and tubes of a heating or cooling coil?
24. What are two characteristics of coil cleaning agents that influence the manner in which they are used?
25. From which side of a coil should one work when applying a cleaning solution?
26. Describe briefly in 3 steps the procedure for cleaning the filters of an air-cooling system.
27. If there is no obvious cause for poor drainage in a heating system, what unit(s) should be inspected immediately?
28. In air-cooling installations, what is used in place of the internal equalizer?
29. On installations not equipped with filters, why must the air intake side of the coils be frequently inspected and cleaned of lint accumulations?

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

ADVANCEMENT TO EN 2

1. In the *Manual of Qualifications for Advancement in Rating*, NavPers 18068, Revised.
2. General Service Rating, or EN.
3. To produce broadly qualified, versatile personnel, who in time of emergency, can be advanced to positions of greater responsibility and authority.
4. The *General Training Course for Petty Officers*, NavPers 10055.
5. To catch mistakes before they result in excessive loss of time, labor, and material.
6. By tying new material in with what the individuals already know, and by showing them how the new material relates to their duties.
7. To avoid monotony and fatigue.

CHAPTER 2

STARTING SYSTEMS

1. Electrical starting and compressed air starting.
2. Sufficient speed and a correct compression ratio.
3. Storage battery, starting motor, generator, and control devices.
4. A dead battery.
5. (1) A cracked case, or jar, (2) failure to replace filler caps, and (3) excessive gassing.
6. (1) Transmit the cranking power to the engine when the starting motor runs, (2) disconnect the starting motor from the engine immediately after the engine has started, and (3) provide a gear reduction ratio between the starting motor and the engine.
7. Bendix drive.

8. Dyer shift drive.
9. The starting motor begins to operate, and the pull-in coil is shunted out.
10. At the time of each engine oil change.
11. The cutout relay.
12. The third brush.
13. Most shunt generators have a cutout relay, a current regulator, and a voltage regulator.
14. The air supply system and the engine system.
15. 600 psi.
16. Strainer.
17. Reducing valve.
18. To clean the air further and add a mist of oil for lubricating the throttle pilot valve.
19. Pilot valves.
20. Check the valve seats and the valves for pitting, cracks, and excessive wear. In addition, check the springs for breakage.

CHAPTER 3

MECHANICAL AND FLUID DRIVES

1. The disk and band styles.
2. A dry-type, twin-disk clutch.
3. Because the gears for forward and reverse rotation of the twin-disk clutch and gear mechanism remain in mesh at all times.
4. When the operating lever is placed forward.
5. Floating plate.
6. The drum and reduction gear shaft rotate in the same direction as the engine crankshaft, causing forward rotation of the propeller.
7. By means of a drilled passage in the crankshaft which supplies oil, as a spray, to the gears and other moving parts.
8. The reverse gear should be disassembled and thoroughly inspected.
9. The brake band is fibre lined and more subject to wear than the metallic disks used for the ahead drive.
10. Wear, insufficient pressure, overload, and fouling.
11. Use a stone for smoothing.
12. Excessive wear and an added load on the entire drive system.

13. By making a check of the free length of the springs.
14. A dry cloth should be used on the clutch facings.
15. Mating clutch surfaces may become scored.
16. Defective clutch mechanism or water in the clutch linings.
17. Allow the wet molded linings to dry with the clutch in the disengaged position.
18. The fouling of the linings by oil, grease, or water.
19. In order to have the clutches rotate with the engine at all times, and at engine speed.
20. To delay the inflation of the clutch to be engaged.
21. 100 psi.
22. To allow time for the forward clutch to deflate and become disengaged before you start inflating the reverse clutch.
23. The defective parts must be replaced.
24. A pressurestatic contact maker.
25. Plugging of the pressure relief nozzles.
26. Keep the oil system free from all foreign matter.
27. By operating the dumping control several times.
28. A dog clutch.
29. Misalignment.
30. The temperature is increased.

CHAPTER 4

DIESEL-ELECTRIC DRIVES

1. Diesel-electric d-c drive.
2. Because some of the generating units that are not needed can be shut down completely.
3. By changing the speed of the engine.
4. To ensure reliability and flexibility of operation.
5. Double-armature, slow-speed motor.
6. The propeller rpm and the direction of rotation of the propeller.
7. By means of governors.
8. The generator setup switch should be moved to the "BYPASS" (or "OFF") position as soon as possible. Then the motor field rheostat should be readjusted and the engine-speed controller reset.
9. Secure the defective equipment as soon as possible.

10. Shut down the equipment, deenergize the live circuits, and use CO_2 fire extinguishers.
11. Push the STOP button, reset the overload relay, and push the START button. Watch the starting operation to see that the auxiliary accelerates to normal speed.
12. Move the engine-speed controller to a lower setting temporarily.
13. Deenergize the propulsion loop and the excitation circuits completely.
14. The propeller shaft should be locked.
15. The corresponding propulsion generator should be removed from the series loop.
16. The appropriate officer should be notified as soon as possible.
17. 180° F.
18. The engineer officer and the officer of the deck should be notified.
19. To prevent freezing of the bearing metal to the shaft.

CHAPTER 5

PUMPS

1. To provide automatic timing of the admission and release of steam to and from each end of the steam cylinder.
2. 7 inches.
3. Too short a stroke.
4. By means of the tappet collars.
5. By jacking the pump with a bar.
6. A valve may be broken.
7. Rust in the steam end.
8. Assemble all pertinent blueprints, drawings, and available data.
9. Poor workmanship and assembly, or the rod is so fitted that the shoulder bears against the piston without giving a proper bearing surface for the tapered part of the rod.
10. Soak the packing in hot water for at least 12 hours.
11. Faulty piston rings.
12. The rods and cylinders are scored, and followers and bolts break.
13. The tilting box.

14. The floating ring must be forced off center from the pump shaft.
15. The positive-displacement rotary pump.
16. Rotary pumps are designed with very small clearances between rotating parts, and between rotating and stationary parts.
17. The replaceable inserts take up the wear which would otherwise be sustained by the ends of the lobes. In addition, they maintain a tight seal between the lobe ends and the casing.
18. (1) Number of intermeshing screws involved, (2) pitch (low or high) of the screw, and (3) general direction of fluid flow (simple or double).
19. Open.
20. Air is leaking into the pump suction.
21. Considerable vaporization in the liquid end.
22. Once each quarter.
23. Volute and volute turbine types.
24. To eliminate the need for renewing an entire impeller and pump casing, when worn.
25. To prevent the pumps from overheating and becoming vapor bound, in case the discharge is entirely shut off.
26. About every 2 months.
27. At least every 6 months.
28. Remove the upper half of the bearing.
29. Short in capacity.
30. The pump is overloading the driver.
31. Casing rings and impeller rings, shaft sleeves, bearings, and bushings.
32. The jet pump.

CHAPTER 6

FUEL INJECTION EQUIPMENT

1. To deliver fuel to the cylinders, at the proper time and in the proper quantity, under various engine loads and speeds.
2. Penetration is the distance through which the fuel particles are carried by the kinetic energy imparted to them as they leave the injector or nozzle.
3. (1) Common-rail, (2) individual-pump, and (3) distributor.
4. To maintain a constant pressure in the system, returning all excess fuel to the fuel supply tank.

5. It is lifted mechanically by a system of push rods and cross rods, actuated by a timed camshaft.
6. The clearance existing between the cam and push rod mechanism.
7. Because it is difficult to control accurately the small quantities of fuel injected into each cylinder at each power stroke.
8. Little effort is required to adjust the operating pressure.
9. The Ex-Cell-O fuel system.
10. The plungers are cam-operated.
11. Measuring is done by the centrally located rotor, driven by the drive shaft.
12. Unit-injector system.
13. Unit-injector system.
14. Pintle- and hole-type nozzles.
15. The unit must be disassembled, cleaned thoroughly and each part carefully inspected.
16. Dirt.
17. Special safety filters or screens.
18. The unit, as well as the hands should be rinsed in clean Diesel fuel.
19. The plunger of the pump is sticking and releasing at intervals.
20. By placing a small amount of mutton tallow on the plunger, and then working it back and forth with a rotating motion.
21. Attempt to move the rack by hand after all linkage, to the governor, has been disconnected.
22. Failure to follow instructions given in the engine instruction manual, and in the fuel injection equipment maintenance manual.
23. Check the unit periodically with an appropriate tester.
24. Keep all parts of the body out of line of the fuel spray.
25. Erosion of nozzles or orifices.
26. By bleeding a small amount of fuel from the top of the filter, by slightly loosening the bleeder screw, and checking for cloudiness, which indicates air in the fuel.
27. Remove the filling plugs on top of the filter and pour clean fuel into the filter until all air is displaced. Air not removed by this method can be removed with the hand-priming pump.
28. The suction line of the transfer pump.

CHAPTER 7

CARBURETION AND THE CARBURETOR

1. The throttle valve.
2. A temporarily lean mixture.
3. The accelerating pump provides the additional fuel needed for the accelerating system to furnish the temporarily rich mixture.
4. Economizers or power compensators.
5. Improper adjustments, incorrect float level, and clogged passages.
6. So that the cylinder with the weakest mixture receives a mixture sufficiently rich to ensure complete combustion.
7. Adjust the throttle stop on the carburetor so that the speed is sufficient to prevent the engine from stalling when the load is applied.
8. Slightly to the rich side.
9. The amount of fuel and the timing of the pump are incorrect for the requirements of acceleration.
10. Adjustment of float level.
11. To prevent any accumulation of sediment in the fuel bowl from entering and clogging the jet openings.
12. Compressed air or a soft wooden cleaning rod.

CHAPTER 8

ENGINE MAINTENANCE

1. By creating air spaces or insulation which resist the flow of heat.
2. Visual inspection.
3. By permitting blow-by of combustion gases, which not only increases the temperature but also may reduce the oil film until metal-to-metal contact takes place.
4. The liner should be replaced.
5. These deposits may alter the shape and decrease the volume of the space, preventing proper turbulence and efficient combustion, and resulting in a loss of power.
6. The threads of the studs and the nuts should be carefully cleaned by wire brushing and applying an approved solvent.
7. Piston slap and excessive oil consumption.

8. The crown and lands have a diameter smaller than the skirt, and therefore do not contact the cylinder wall.
9. Too high a temperature reduces the oil viscosity, causing the lubricant to run off the surfaces, while too low a temperature increases the viscosity sufficiently to prevent adequate lubrication.
10. Carbon deposits accumulated above the compression rings.
11. In order that the ring may be free to flex at all operating temperatures.
12. Too high lube oil temperature, oil line leakage, loose bearings, or improper oil.
13. Bright spots on the end of the ring.
14. The dimensions of the free gap are checked.
15. Surface condition, amount of taper, and out-of-roundness of the liner.
16. Scrape the cylinder surface above the ring travel area in order to remove carbon and any lip of a cylinder ridge which may have been formed.
17. Soaking and the use of a brass drift.
18. Avoid taking measurements where areas do not make contact.
19. Uneven wear on the pin and bushing, and piston skirt wear.
20. Ream the bushing.
21. If an excess of cleaning fluid is allowed to settle in the cylinder, an explosion may occur.
22. The lodging of small particles of carbon between the valve head and the valve seat.
23. By preventing the heat from being conducted away which results in high temperatures that deform the insert.
24. A groove may be formed in the valve, so that it will not make contact with the ground surface of the seat when the parts become hot.
25. Excessive grinding produces a sharp edge which is incapable of transferring heat away at a rate sufficient to prevent burning.
26. Corrosion and metal fatigue.
27. Clogging which results from the formation of carbon deposits.
28. Wear.
29. Insufficient oil in the cylinder of the hydraulic lash adjuster.
30. Since the parts are not interchangeable, only one unit should be disassembled at a time.

31. Upper half.
32. Torsional vibration of the shaft.
33. See that the engine and the driven unit are aligned properly and avoid overspeeding of the engine.
34. By the minute pits covering the surface.
35. A fine oil stone and a piece of crocus cloth.
36. As far as possible from the axis of the crank pin.
37. Top dead center; inboard; near or at bottom dead center; and outboard.
38. Use a gage to measure the stretch or elongation of each bolt.

CHAPTER 9

TESTING OF FUEL AND LUBRICATING OILS

1. The tendency of an oil to resist flow or change of shape.
2. Temperature of the oil tested, and the number of seconds required for the oil to pass through the orifice.
3. In the size of the discharge orifice.
4. 122° F.
5. The change is towards a lower viscosity because of dilution with fuel oil.
6. 100° F.
7. Tilt the end of the visgage down at about an angle of 30°.
8. When it has 5 percent dilution.
9. The lowest temperature at which an oil will barely flow from a container.
10. By the open-cup and the closed-cup methods.
11. The temperature at which the oil will continue to burn when ignited.
12. Because some of the more volatile products are driven off during the first test.
13. Autogenous ignition point.
14. The engine can be started more easily.
15. A special single-cylinder test engine with a variable compression ratio.
16. That the ignition-delay period in a given engine, at a fixed speed, decreases with an increase in the compression ratio.
17. Because of the potential hazards associated with its use.
18. The ability of an oil to separate cleanly from any water present.

19. To determine the amount of water and sediment in the oil.
20. Ash content.
21. By a system of symbols.
22. The mineral type; and the compounded, or additive, type.
23. Symbol 1150 (SAE 7).
24. They improve the ability of the oils to lubricate in the presence of water and steam.
25. 9000 series.
26. Symbol 8190.

CHAPTER 10

GAS TURBINE ENGINES

1. Two gas turbine engines, a combining reduction gear, and a d-c generator.
2. Two sections.
3. Gas flow which, in turn, is governed by the amount of fuel burned.
4. A gate type valve, in each of two ducts.
5. A centrifugal switch which automatically stops the engine in the event of overspeed.
6. By a combining reduction gear.
7. The governor (fuel control governor).
8. Between 50 and 200 psi.
9. 15 psi.
10. Starting, ignition, indicating, warning, and safety circuits.
11. By the safety circuit or whenever the throttle is unlocked.
12. The master switch must be turned off so that the actuated relay is reset and continuity of the circuit restored.
13. The exhaust back-pressure valve.
14. Push the throttle inward, continue to press the "START" switch for a few seconds in order to clear the combustion chambers and allow accumulated fuel to be discharged through the nozzle box drain line.
15. The engine will shut down automatically.
16. The other engine should be stopped by following the normal shutdown procedure.
17. The overrunning clutch.
18. Bending the heat shield to obtain sufficient clearance.

19. An orifice.
20. 70 psi.
21. After it has been operated a total of 150 hours.
22. 2300 rpm.
23. The parts can be cleaned with a stainless steel wire brush, emery paper, stainless steel wool, or cleaning solvent.

CHAPTER 11

AUXILIARY MACHINERY AND EQUIPMENT

1. Because explosive fumes may collect in the compressor or air receiver.
2. A defective discharge air valve.
3. Dirty intake air, excessive use or improper grade of cylinder oil, or excessively high air temperature resulting from faulty cooling.
4. Make certain that suction valves open TOWARD, and discharge valves AWAY FROM, the center of the cylinder.
5. A turn of solder or fuse wire should be placed around the screw and set down into a recess by the locking nut.
6. Loosen the piston rod locknuts adjacent to the crosshead, unscrew the piston rod from the crosshead, and lift the piston and the rod out of the cylinder.
7. Accurate measurements of the cylinder liners should be taken.
8. When they are worn to the point of becoming noisy.
9. To prevent dust and grit from being carried into the valve chamber, and to remove gummy deposit which comes from the oil used in the compressor cylinders.
10. Dust-laden intake air or excessively high temperatures caused by leaking or dirty valves.
11. Secure the compressor.
12. (1) Electrical, by means of an a-c synchronous transmission system; (2) hydraulic, by means of a hydraulic telemotor system.
13. The air cocks must be opened, the charging pump operated until oil escaping from these air cocks is free of bubbles, and then the air cocks closed.
14. From —24° to —40° F.
15. To prevent small amounts of water (or air bubbles) and other foreign matter from entering the system.

16. By changing the angle of the tilting box in the hydraulic pump.
17. Keep the exposed parts covered with a coat of thin-film rust-preventive compound, or other heavy oil; construct protective guards over the exposed parts of the rams; and secure or remove loose gear.
18. About every six months.
19. Compression of brake linings.
20. A winch has a horizontal shaft and a capstan has a vertical shaft.
21. (1) Regular operation, (2) proper lubrication, (3) proper maintenance of all the units, and (4) cleanliness of the fluid.
22. Shut down the engine and determine the cause of the trouble.
23. Drain all water jackets.
24. Once each month.
25. The thermostatic element should be replaced.
26. The tank should be filled manually before making the initial start.
27. By overspeeding the engine temporarily and tripping the valve mechanism.

CHAPTER 12

DISTILLING PLANTS

1. Full output cannot be maintained.
2. 16 inches Hg vacuum to approximately atmospheric pressure.
3. To keep scale formation at a minimum, and to be able to operate the plant at full capacity.
4. Air leakage, low water levels in the evaporator shells, improper venting of the evaporator tube nests, scale or other deposits on the evaporator tubes, and poor drainage of the evaporator tube nests.
5. Capacity and economy losses.
6. A hydrostatic test of the first-effect steam circuit should be made.
7. Improper venting of the evaporator tube nests.
8. The use of some shore waters causes a tough adherent scale to form on the evaporator tubes.
9. There will be an increase in the rate of scaling of the evaporator tubes and the quality of the distillate may be impaired.

10. The brine pump and piping system should be inspected to determine the cause of the trouble.
11. The purpose of cornstarch is to minimize priming, and the purpose of the boiler compound is to combat tube scaling.
12. Differential expansion and contraction which breaks the scale loose from the tubes.
13. Once each day.
14. Air leaks.
15. Insufficient steam pressure or wet steam at the air ejector nozzle.
16. The distilling condenser vacuum.
17. When the plant is properly operated and a full flow of circulating water is being maintained.
18. Excessive salinity of the distillate.
19. By means of an air pressure or a hydrostatic test, in accordance with the recommended procedure in the manufacturer's instruction book.
20. Naval shipyard, or tender.
21. The nature of the deposit.
22. The output of the plant will be reduced considerably.
23. The recommended interval between cleanings should be at least 6 months.
24. By means of lifting gear (suitable to the type of installation).
25. Expansion and contraction caused by the heat may cause the tubes to loosen at their joints.
26. Vapor compression distilling plants.
27. It is hard to keep clean and to overhaul.
28. 1½ to 2 hours.
29. When alongside a tender or at a base where special equipment is available.
30. By the use of copper scrapers and brushes.
31. After each 500 hours of operation.
32. The cleaning tools are the carbide-tipped cutter bit, the expanding wire brush, and the vibrating head.
33. Two or three tubes.
34. The tubes must be cleaned every 250 hours of operation.
35. Grinding.

CHAPTER 13

MAINTENANCE OF REFRIGERATION EQUIPMENT

1. Diaphragm or ring plate types.
2. Forced feed lubrication or splash lubrication.
3. By means of crankshaft seals.
4. The receiver.
5. Silver-soldering or brazing.
6. The packed stem and the packless stop valves.
7. The solenoid valve.
8. The king solenoid valve.
9. A refrigerant control manifold.
10. When the flow of refrigerant has been stopped by the solenoid valves (approximately at 2 psi).
11. The water failure switch.
12. 3/16 inch.
13. Hot gas defrosting lines.
14. Testing the entire system for leaks.
15. The halide torch.
16. Pump down the Freon pressure, within the part of the system to be opened (½ to 5 psi above atmospheric pressure).
17. Sufficient refrigerant must be immediately bled into the evacuated part of the system to raise the pressure to between ½ and 2 psi.
18. When charging or adding Freon-12 to the system to compensate for leak losses, or when the presence of moisture in the system is suspected.
19. Immediately before the compressor starts, after a temporary or prolonged shut-down period.
20. Check for air in the system.
21. If the temperature of the liquid leaving the receiver is more than 15° F lower than the temperature corresponding to the discharge pressure.
22. After the condenser has been properly purged.
23. Leaks may develop, resulting in loss of the Freon-12 charge and admission of salt water into the system.
24. At least once every two weeks.
25. Because the compressor crankcase is under a slight pressure.
26. After each cleaning of the compressor suction scale trap.

27. Belt dressing should never be used.
28. Either a gradual or a sudden decrease in the normal compressor capacity.
29. By pumping down the compressor to 2 psi gage, then stopping the compressor, and quickly closing the suction and discharge line valves.
30. The entire discharge valve assembly should be replaced.
31. After the compressor has been in operation for at least three days.
32. The manufacturer's instruction book.

CHAPTER 14

VENTILATION AND AIR CONDITIONING

1. As the temperature rises, the amount of moisture that the air can hold increases.
2. The ratio of the weight of water vapor in a sample of air to the weight of water vapor required to saturate that given amount of air.
3. Sensible heat and latent heat.
4. The wet-bulb depression.
5. When the air is saturated.
6. 52 percent.
7. The body gains heat (1) by radiation, (2) by convection, (3) by conduction, and (4) as a byproduct of physiological processes that take place within the body.
8. About 45 percent by radiation, 30 percent by convection and conduction, and 25 percent by evaporation.
9. Effective temperature.
10. 40 to 50 percent.
11. A comfort chart.
12. To drain out onto the weather deck the water which has entered the sump of the ventilators.
13. Vaneaxial ventilating fans.
14. The refrigerant circulating system, the chilled-water circulating system, and the unit cooler system.
15. Duct coils, gravity coils, and unit cooler coils.
16. Zone heating system.

17. It should have the same face area (finned space) and shape, the same number of fins per lineal inch of tube length, and the same number of rows of tubes in the air flow direction.
18. To heat the supply of air near the intake and therefore prevent the ducts from sweating.
19. Convector heaters.
20. Unit heaters.
21. There will be an increase in dirt and odors taken inboard.
22. Make a check list of all the parts.
23. The coil should be washed with a recommended cleaning agent.
24. They are nontoxic and volatile.
25. The air discharge side of the coil.
26. Tap on a hard surface to loosen dirt; blow compressed air through from discharge side; use cleaning solution.
27. The steam trap(s).
28. A thermostatic expansion valve with an external equalizer.
29. If such accumulations are allowed to remain, there will be a marked decrease in the air flow, and a great reduction in the unit's heating capacity.

APPENDIX II

QUALIFICATIONS FOR ADVANCEMENT IN RATING

ENGINEMEN (EN)

Rating Code No. 3800

QUALS CURRENT THROUGH CHANGE 8

General Service Rating

Scope

Enginemen operate, maintain, and repair internal combustion engines; operate and maintain auxiliary engine room, refrigeration, and air conditioning equipment.

Emergency Service Ratings

ENGINEMEN D (Diesel Enginemen), Rating Code No. 3801--- **END**
Operate, maintain, and repair Diesel main propulsion and auxiliary engines and equipment.

ENGINEMEN G (Gasoline Enginemen), Rating Code No. 3802-- **ENG**
Operate, maintain, and repair gasoline main propulsion and auxiliary engines and equipment.

Navy Job Classifications and Codes

For specific Navy job classifications included within this rating and the applicable job codes, see Manual of Enlisted Navy Job Classifications, NavPers 15105 (Revised), codes EN-4300 to EN-4399.

Qualifications for Advancement in Rating

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
100 PRACTICAL FACTORS			
101 OPERATIONAL			
1. Start, operate, stand watch on, and secure refrigeration and air conditioning systems-----	3	3	3
2. Stand watch in steering engine room----------	3	3	-----

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
3. Use radiac instruments and perform monitoring operations on intake lines and evaporators	3	3	3
4. Engage and disengage jacking gear on Diesel engine	3	3	----
5. Start, operate, and secure all hydraulic equipment	3	3	----
6. Line up lubricating oil system	3	3	----
7. Circulate lubricating oil through engine with stand-by lubricating oil pump	3	3	----
8. Start, operate, and secure fire and flushing pump	3	3	3
9. Locate principal isolation valves of fire main system	3	3	3
10. Line up, start, operate, and secure lubricating- and fuel-oil purifiers and centrifuges	3	3	----
11. See that oil is delivered to reduction gears and thrust bearings. Inspect for leaks	3	3	----
12. Open drains to whistle and siren	3	3	----
13. Cut in air to whistle and siren	3	3	----
14. Take and log counter readings	3	3	----
15. Start, operate, and secure a vapor compression distilling plant	3	3	----
16. Detect high- or low-lubricating oil pressure	3	3	3
17. Start, operate, and secure Diesel generators	2	2	----
18. Bleed fuel lines to injectors	2	2	----
19. Heat lubricating oil in sump tank to 90° F and secure heating coils	2	2	----
20. Make operational adjustments to clutches on small boat engines	2	2	2
21. Correct unusual or erratic operation of gasoline engines	1	----	1
22. Correct unusual or erratic operation of Diesel engines	1	1	----
23. Obtain permission from bridge, and turn main engines	1	1	----
24. Time ignition systems on gasoline engines	1	----	1
102 MAINTENANCE AND/OR REPAIR			
1. Clean strainers and change filters on Diesel engines	3	3	----

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
2. Clean strainers and change filters on gasoline engines	3	-----	3
3. Lubricate all pumps and compressors (except refrigeration compressors)	3	3	3
4. Remove scale from evaporator tubes by cold shocking	3	3	-----
5. Spot and grind in valves	3	3	3
6. Renew bonnet gaskets in valves	3	3	3
7. Replace zinc plates in all salt water cooling systems	3	3	-----
8. Clean salt waterside of heat exchangers in main engine	3	3	---
9. Change oil and lubricate Diesel generators	3	3	-----
10. Remove scale from evaporator tubes chemically	2	2	-----
11. Fit piston rings to cylinders of reciprocating pumps	2	2	-----
12. Test and renew suction and discharge valves on compressors	2	2	2
13. Use dial indicators, micrometers, bridge gages, depth gages, and inside-outside vernier calipers to take clearances on journals, bearings, liners, and pistons	2	2	2
14. Check for noncondensable gases and pump down refrigerant systems	2	2	2
15. Use halide torch to test for leaks on refrigeration or air conditioning equipment	2	2	2
16. Reface valve seats and discs	2	2	2
17. Lubricate refrigeration compressors	2	2	2
18. Repack high-pressure valves	2	2	-----
19. Spot in and replace bearings of centrifugal pumps	2	2	-----
20. Dehydrate, test, and recharge refrigeration systems	1	1	1
21. Replace oil seals on refrigeration compressors	1	1	1
22. Maintain and repair small boat clutches, transmissions, drive shafts (including alignment), and stern tube glands	1	1	1
23. Determine clearance of bearing in pumps, and check alignment of couplings	1	1	-----

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
24. Set all reducers and relief valves to required pressure	**1**	1	1
25. Take clearances and replace wearing rings on centrifugal pumps	**1**	1	-----
26. Check for alignment of centrifugal pump driving unit	**1**	1	-----
27. Test evaporator tubes hydrostatically for leaks	**1**	1	-----
28. Operate an engine lathe for cutting threads and tapers, and plain turning	**1**	1	1
29. Test fuel injection valves	**1**	1	-----
30. Take clearances on blower lobes	**1**	1	-----
31. Take clearances on blower gear train	**1**	1	-----
32. Maintain pumps and associated equipment in hydraulic systems	**1**	1	-----
33. Take reduction gear bearing clearances, thrust clearances, and Kingsbury thrust bearing clearances	**1**	1	-----
34. Check and adjust constant-speed and speed-limiting governors and overspeed trips	**1**	1	-----
35. Inspect propellers, shafts, sea valves, zincs, and strut and stern tube bearings when ship is in drydock	**C**	C	-----
36. Plug and replace condenser tubes	**C**	C	-----
103 ADMINISTRATIVE AND/OR CLERICAL			
1. Locate and use appropriate sections of BuShips *Manual*, manufacturers' instruction books, and handbooks to obtain necessary data when repairing machinery	**1**	1	1
2. Supervise and train personnel in operation, maintenance, and repair of:			
a. All engine room equipment	**C**	C	C
b. Refrigeration and air conditioning equipment	**C**	C	C
3. Take charge of an engine room watch on Diesel-driven ship under way	**C**	C	-----
4. Keep engine room records and prepare naval shipyard and tender work requests	**C**	C	C

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
5. Estimate time and material needed for repair of auxiliary and main propulsion machinery	C	C	C
6. Supervise and make out reports for full power, economy, dock, and post-repair trials	C	C	C
200 EXAMINATION SUBJECTS			
201 OPERATIONAL			
1. Safety precautions involved in performing the tasks appropriate to the applicable rates listed under 100 practical factors			
2. Causes and prevention of crankcase explosions	3	3	-----
3. First-aid procedures in cases of electrical shock, heat exhaustion, and exposure to refrigerants in liquid or gaseous states	3	3	3
4. Safety precautions to be observed when working on shipboard machinery, taking on fuel, and moving or lifting heavy objects	3	3	3
5. Safety precautions involved when refueling and starting gasoline-powered small boats	3	-----	3
6. Safety precautions required when testing injectors	3	3	-----
7. Principles and operation of the following:			
a. Four-stroke cycle engine	3	3	3
b. Two-stroke cycle engine	3	3	-----
c. Double acting engine	3	3	-----
d. Opposed piston engine	3	3	-----
e. Single acting engine	3	3	3
8. Meaning and significance of:			
a. Compression ignition principle	3	3	3
b. Diesel cycle	3	3	-----
c. Power stroke	3	3	3
d. Exhaust stroke	3	3	3
e. Scavenging	3	3	-----
f. Turbulence	3	3	3
g. Precombustion	3	3	-----
h. Supercharging	3	3	-----
i. Internal combustion engine	3	3	3
j. True Diesel engine	3	3	-----
k. Semi-Diesel engine	3	3	-----
l. Otto cycle	3	-----	3

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
9. Capacity and limitations of fire-fighting equipment driven by gasoline engines	3	----	3
10. Capacity and limitations of fire-fighting equipment driven by Diesel engines	3	3	----
11. Trace path of lubricating oil through a Deisel engine	3	3	----
12. Trace path of lubricating oil through a gasoline engine	3	----	3
13. Trace path of cooling water through an internal combustion engine (open system and closed system)	3	3	3
14. Principles of operation of ignition systems on gasoline engines	3	----	3
15. Principles and use of compression, oil-control, and oil-scraper piston rings	3	3	3
16. Standards to be followed in determining hardness, alkalinity, and salinity of water	3	3	3
17. Purpose and principles of operation of:			
a. Reduction gears	3	3	3
b. Distilling plants	3	3	3
c. Three-stage air compressors	3	3	3
d. Lubricating oil purifiers	3	3	3
e. Exhaust silencers	3	3	3
f. Air coolers	3	3	----
g. Reciprocating, gear, and centrifugal pumps	2	2	----
h. Jacking gears	2	2	----
i. Relief valves	2	2	2
j. Diesel generators	2	2	----
k. Hydraulic couplings	2	2	----
l. Air starting systems	2	2	----
m. Principles and operation of electrical starting systems	2	2	2
18. Procedures involved in making the following tests on fuel and lubricating oil:			
a. Viscosity	2	2	2
b. Flash point	2	2	2
c. Fire point	2	2	2
d. Cetane	2	2	2
e. Water and sediment	2	2	2

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
19. Procedures to be followed when these symptoms appear on gasoline engines:			
a. Hunting	1	-----	1
b. Engine misses	1	-----	1
c. Engine fails to start	1	-----	1
d. Engine starts but will not run continuously	1	-----	1
e. Engine runs unevenly	1	-----	1
f. Engine will not turn over	1	-----	1
g. Engine stops suddenly when running	1	-----	1
h. Unusual noises in engine	1	-----	1
i. Engine runs with ignition switch off	1	-----	1
20. Procedures to be followed when these symptoms appear on Diesel engines:			
a. Hunting	1	1	-----
b. Failure to start	1	1	-----
c. Contamination of fuel oil, lubricating oil, and cooling water	1	1	-----
d. Engine will not turn over	1	1	-----
e. Low or high firing pressure	1	1	-----
f. Loss of lubricating oil pressure	1	1	-----
g. Low scavenging air receiver pressure	1	1	-----
h. High exhaust back pressure	1	1	-----
i. Excessive smoke	1	1	-----
j. High cylinder temperature	1	1	-----
k. Low cylinder temperature	1	1	-----
l. Excessive vibration	1	1	-----
21. Causes and prevention of:			
a. Excessive and undue piston wear	1	1	1
b. Cracked piston	1	1	1
c. Broken lands	1	1	1
d. Piston skirt seizure	1	1	1
e. Excessive ring groove clearances	1	1	1
f. Clogged oil holes	1	1	1
g. Worn piston pin bushing	1	1	1
h. Too high lubricating oil temperatures	1	1	1
i. Lubricating oil line leakages	1	1	1
j. Loose connecting rod bearings	1	1	1
k. Misaligned connecting rods	1	1	1
l. Out-of-round cylinder bore	1	1	1
m. Scored journals	1	1	1

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
21. Causes and prevention of—Continued			
n. Journal bearing failures	1	1	1
o. Damaged shaft or thrust bearings	1	1	1
22. Construction and operation of Freon-12 type of refrigerating units. Characteristics of refrigerants	1	1	1
23. Purpose and principles of operation of:			
a. Refrigeration expansion valves	1	1	1
b. Thrust bearings	1	1	1
c. Governors	1	1	1
d. Overspeed trips	1	1	1
24. Emergency procedures in starting Diesel engines	C	C	----
25. Principles of operation of the common rail, distributor (Bosch), and individual unit injector systems	C	C	----
202 MAINTENANCE AND/OR REPAIR			
1. Purpose and procedures for cold shocking evaporators	3	3	----
2. Procedures to be followed when:			
a. Changing and cleaning fuel and lubricating oil strainers and filters	3	3	3
b. Lubricating Diesel electric generating equipment	3	3	----
c. Repacking stuffing boxes on centrifugal pumps	3	3	3
d. Replacing zinc plates in main and auxiliary heat exchangers	3	3	3
e. Removing scale from evaporator tubes	2	2	----
f. Testing and renewing suction and discharge valves on compressors	2	2	2
g. Spotting in and replacing bearings of centrifugal pumps	2	2	2
h. Renewing cylinder liners	2	2	2
i. Renewing pistons and rings in internal combustion engines	2	2	2
3. Methods of taking oil clearances in bearings	2	2	2
4. Methods of testing evaporators and condensers for salt water leaks	2	2	2

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
5. Principles of operation of the following gasoline engine units:			
a. Distributors	2	-----	2
b. Flywheels	2	-----	2
c. Starting motors	2	-----	2
d. Fuel pumps	2	---	2
e. Carburetors	2	-----	2
f. Spark plugs	2	-----	2
g. Generators	2	-----	2
h. Ignition coils	2	-----	2
i. Batteries	2	-----	2
j. Lubricating oil pumps	2	-----	2
k. Water pumps	2	-----	2
l. Transmissions	2	-----	2
6. Methods of grinding, refacing, and setting intake and exhaust valves	2	2	2
7. Lubricant requirements and precautions when handling dehydrated oils for refrigerant systems	1	1	1
8. Procedures to be followed when:			
a. Repairing centrifugal pumps	1	1	-----
b. Taking clearances and renewing parts on centrifugal pumps	1	1	-----
c. Checking alignment of centrifugal pump driving unit	1	1	-----
d. Dehydrating, testing, and recharging refrigeration systems	1	1	1
e. Disassembling, cleaning, replacing, repairing, and assembling fuel oil injection valves	1	1	-----
f. Replacing oil seals on refrigeration compressors	1	1	1
g. Methods of testing and adjusting fuel oil injection valves	1	1	-----
9. Methods of testing refrigerating systems, including compressors, for proper operation	1	1	1
10. Procedures to be followed when pulling:			
a. Liners	1	1	1
b. Pistons	1	1	1
c. Cylinder heads	1	1	1
d. Wrist pins	1	1	1
e. Piston rings	1	1	1
f. Bearings	1	1	1

Qualifications for Advancement in Rating	APPLICABLE RATES		
	EN	END	ENG
11. Factors governing main propulsion plant efficiency; causes of poor performance, and appropriate remedies	C	C	C
12. Causes of inefficient operation of refrigerating systems, and corrective procedures	C	C	C
13. Procedures for checking and adjusting constant-speed and speed-limiting governors and overspeed trips	C	C	-----
14. Methods of taking main engine and reduction gear bearing clearances and thrust clearances	C	C	-----
15. Purpose, study, and interpretation of Diesel engine indicator cards	C	C	
203 ADMINISTRATIVE AND/OR CLERICAL			
1. Duties and responsibilities of the engineer officer of the watch	C	C	C
2. Performance and casualty reports required by BuShips and Chief of Naval Operations, and all records to be kept by the engine room	C	C	C
3. Selection, procurement, and use of packings, greases, oils, polishes, cleaning materials, spare parts, and other engine room supplies	C	C	C
4. Use of allowance lists and procedures for maintaining inventories and obtaining replacements	C	C	C
5. Application of damage control principles	C	C	C
6. Knowledge of administrative, material, and operational readiness inspections	C	C	C

INDEX

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